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QUATERNARY GEOMORPHOLOGY OF THE QUEBEC NORTH SHORE, GODBOUT TO SEPT-ILES

by

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presented to the University of Waterloo
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QUATERNARY GEOMORPHOLOGY OF THE QUEBEC NORTH SHORE,
GODBOUT TO SEPT-ILES

L.A. Dredge

Abstract

This report presents a summary of the physical properties of surficial deposits, evolution of the landscape and economic aspects of the materials. Surficial geology maps of the Sept-Iles and Cap Chat map sheets, at a scale of 1:125,000, accompany the text.

The work was carried out by field investigations and air photo interpretation, combined with laboratory analyses of samples collected.

The Quaternary deposits of the North Shore are the product of the last glacial episode and postglacial processes. The main materials are gravelly till and outwash, estuarine nearshore deltaic sand and offshore clay, littoral sand, aeolian sand, peat and alluvium.

Evidence from striae and flutings, indicator mineralogies and till fabrics indicates that the main direction of ice flow was towards the south-southeast over the entire area, although there is evidence of an earlier and a very late easterly flow along portions of the south coast adjacent to the Laurentian Trough.

Deglaciation occurred about 10,000 years ago at Sept-Iles. The marine limit is at an elevation of 130 m in that area but declines towards the southwest to 100 m at Godbout. From the time of deglaciation the landscape above the marine limit was altered by the deposition of a thin layer of gravelly granitic till as the ice sheet retreated northward. A belt of moraines extending across the field area from the Toulnustouc River to the Moisie River marked interruptions in the retreat.

Below the marine limit the landscape evolved through the deposition of a marine offlap sequence. Large coalescing deltas were built into the Goldthwait Sea during the first 1500 years after deglaciation. Rock flour was carried out into the offshore environment and was deposited as banded or massive silty clay. Landslides occur where these deposits are presently found at, or near, the surface.

A tentative correlation of events and materials has been suggested by comparing the results of this study with those in other areas of the Gulf of St. Lawrence, the St. Lawrence Lowlands, and the Labrador Plateau. Direct correlation is difficult because of the large distances involved and the shortage of chronological control on the North Shore. The morainic belt is directly linked to moraines reported to the west and east of the field area.

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1. INTRODUCTION

1.1 General Statement on Quaternary Research in Boreal Areas

This thesis is a regional reconnaissance study of Quaternary landforms and materials in the boreal region of eastern Quebec, specifically between Godbout and Sept-Iles. Thesis projects are not often undertaken in such areas, because there is usually very little previous information to form a basis for formulating a research problem, there are very few exposures which typify materials and provide good stratigraphical control, and because movement and terrain observation within the closed-crown forest is often very difficult. Therefore, the rationale for undertaking this project, despite these severely limiting constraints, is set out below.

The Canadian Shield is a region with distinctive physiographic and geologic characteristics. Yet, despite its great extent and its uniqueness (in a North American context) only a small percentage of its surficial deposits have been mapped at a scale greater than 1:500,000. With the exception of the Hamilton River region and parts of Ontario, the taiga portion has been especially neglected (see Table 1-1).

Table 1-1: Status of mapping of surficial deposits on the Canadian Shield (Canada, Background study for the Science Council, 1971)

Shield	% area	% mapped at greater than 1:500,000	% mapped at less than 1:500,000	% unmapped
tundra	32	0	29	3
woodland	36	1	12	23
taiga	32	1	11	20
total	100	2	52	46

Despite this general lack of basic information about both the surficial and subsurface materials, parts of the Shield will probably undergo economic and industrial development in the next twenty years. Some schemes, such as the original Rohmer Mid-North Corridor concept, are still conjectural, but problems associated with mining, transportation, timber harvesting, and hydroelectric power development are presently upon us.

From the experience of the Mackenzie Valley studies in which environmental concerns were only considered after considerable industrial expenditure and political negotiating had occurred, it is apparent that regional information about materials and their distribution must be available beforehand if these northern regions are to develop in a rational way, rather than in a random and unplanned fashion. The Science Council of Canada has also recognized this need in stating that:

> ... studies must be carried out in advance of construction so that the results can be fully utilized in planning and design phases of engineering. (Canada, Background study for the Science Council, 1971, 233)

The Council further emphasizes the need for geomorphic research:

> Of particular concern in land use planning are the common unconsolidated earth materials that mantle the bedrock. Scientific knowledge of these materials and associated terrain features is required in development and planning...In addition, knowledge of these materials is of increasing importance in the mineral industry, not only because they are essential mineral commodities but also because of their role in the glaciated Canadian terrain in the interpretation of...geochemical and mineral indication data in the search for mineral deposits.
>
> In view of the above, a concerted effort must be made to bring knowledge of unconsolidated earth materials and associated terrain features up to a level appropriate to present needs for planning and development throughout the country. (Canada, Background study for the Science Council, 1971, 265)

This project was undertaken in an attempt to understand the surficial physical environment of at least a small part of the boreal region and to gain some insight into kinds of problems which will be encountered in these areas.

1.2 The North Shore Example

The Quebec North Shore[1] is particularly appropriate for study because the terrain is representative of much of the boreal region of the Shield, and its developmental problems are imminent.

The region between Baie Comeau and Sept-Iles is covered by a mixture of typical closed-crown coniferous forest and open lichen-woodland, which occupies two basic landscape types: a Shield upland and a coastal plain, the latter being of lesser extent but more likely to be developed first.

The coastal plain of the North Shore is a transport and power corridor. Both the only public road and the Labrador power line traverse the area. Along this axis a string of settlements provides service and processing facilities for local industries related to fishing and lumbering, and acts as trans-shipment centres for communities to the north. Problems associated with economic development have already been encountered; hence, research here can be justified on the basis of present day practicality rather than on future conjecture.

The following list of problems illustrates the need for basic geomorphic research.

---

[1]The southern part of Labrador-Ungava which lies along the north shore of the Gulf of St. Lawrence is generally known as the North Shore (La Côte Nord).

1. The Moisie bridge connecting the scattered eastern settlements with the rest of Quebec was built on one of the few river sites subject to catastrophic mass movements.

2. The location initially chosen for a pelletizing plant at Sept-Iles was on the shore along the only part of the beach that was actively eroding. The location of the associated tailings pond was determined by extrapolating borehole data beyond the sandy formation into which the test holes were drilled, out onto postglacial marine clays.

3. The Churchill Falls power line is strung over the coastal terraces by placing pylons on the slopes of least gradient. At Port Cartier these slopes are on landslide slump blocks which could be reactivated, since the right of way has been stripped of vegetation.

4. One lumber company at Rivière Pentecôte built a small weir which diverted a creek flowing on a terrace composed of valley-fill estuarine deposits. The diversion caused rapid erosion of the terrace and subsequent sedimentation in the main river. The presence of the new alluvial fan shifted the main channel of Riv. Pentecôte, which then undercut the 70 metre high river bank opposite. The collapse of these sandy cliffs produced shifting sand bars along the lower reaches of the river and filled the harbour. Lumber is now trucked to Baie Trinité and Baie Comeau for trans-shipment because the harbour is of little use.

5. During the period of field study for this thesis, some of the lumber tracks in clear-cut areas appeared to be undergoing accelerated gullying and sheet erosion.

The situation then, is that the area is developing rapidly with little understanding of the nature and distribution of surficial materials, or of processes acting to change them, without regard to the effects of human activity on the landscape, and with no appreciation that the materials are not in equilibrium with the present environment.

1.3 A Quaternary Approach to the Problem

In this project, surface materials are described according to, and in order of, their genesis. An historical approach seemed to be the most appropriate format for a reconnaissance study of this sort since:

(1) a genetic map of the unconsolidated deposits provides systematic information about the principal properties of the materials as well as explaining their origin.

(2) the physical nature and behavioural properties of the unconsolidated materials are a function of the inherent initial properties of the source materials, and the forces that have been applied to that material over time. Two of the major types of geomorphic forces operating in this area were glaciation and the postglacial marine transgression. An understanding of these events is therefore a means of predicting the physical and distributional attributes of surficial materials within this area and of similar areas not directly examined in the field.

(3) the Sept-Iles area is particularly interesting from a Quaternary standpoint. Regional information is generally lacking; and the North Shore lies amidst three areas with different glacial histories - the Gulf of St. Lawrence, the St. Lawrence lowlands, and the Labrador plateau.

1.4 Previous Work in the Area

Published references to the main elements in the landscape, and the general configuration of the coast, date back to the reports of Cartier (1536) and Champlain (1608). It is not until recently, however, that systematic geological work has been undertaken, and for the most part these surveys make only passing reference to the unconsolidated materials in the area.

Bayfield (1840) was one of the first visitors who noted geological conditions along the North Shore. As well as mentioning the main rock types along the coast between the Saguenay River and Cape Whittle, he also called attention to stratified valley deposits along the lower reaches of major rivers and the flight of raised beaches at Sept-Iles.

H.Y. Hind (1864) later made observations along the Moisie River in 1862, and he correctly attributed some of the unconsolidated deposits to the work of glaciers. James Richardson (1870) described the bedrock along the North Shore between the Saguenay and Sept-Iles, confining his observations to the coast. He identified the principal rock types in the area, including small Paleozoic outliers. Henri Puyjalon (1880-81) conducted a similar survey for the Quebec government although his principal aim was to search for deposits of economic minerals. Hunt (1886), Obalski (1901), Dulieux (1912), and Faessler and Schwartz (1941) have reported on the deposits of iron ore, particularly the titanium and magnetite-rich gabbro in the Lac des Rapides area and the iron-bearing sands at Moisie. In 1922, Kindle noted the elevation of sandy terraces lying in front of the Laurentian plateau, but he incorrectly assumed that the marine limit was at an elevation of 200 feet.

Carl Faessler (1933 a, b; 1942 a, b; 1945; 1948) has mapped the area between Godbout and Moisie by coastal and river traverses; he concentrated on the bedrock geology and only mentioned the width of the sand plain. Little mapping has been carried out in the inland area except for levelling the profiles of Rivière des Rapides and Rivière Moisie (Québec, Commission des Eaux Courantes, 1948 and 1951), and Moyer's preliminary map of the Lac Vermette area (northwest of Port Cartier) (Moyer, 1959).

In 1931 Bowman published a palynological report on the Matamek peat bog, but detailed work involving the inorganic surficial deposits was not conducted until the mid 1950's, when Laverdière studied the major landforms between Rivière Moisie and Rivière Ste Marguerite (Laverdière, 1954, 1955). Two papers have been published on the characteristics and behaviour of some of the sediments along the Quebec North Shore and Labrador (QNS&L) Railway north of Sept-Iles (Pryer and Woods, 1959; Woods, Pryer and Eden, 1959). Since that time additional information about the sediments has become available from boreholes at townsites and bridge sites, and a coastal classification project has been completed by Dubois (1973).

R.J. Mott is presently completing a pollen study of a small pond near Lac Walker (Mott, 1976), and T. Moore is completing a study of the ironpan in the soil of the Sept-Iles area (Moore, 1976).

These studies, previously undertaken, have supplied information on bedrock geology and provided scattered data about unconsolidated materials. The summary above shows that there have been no basic regional surveys of the unconsolidated deposits. There is also a dearth of information about glacial activity in the area, particularly events and their timing from the disappearance of the ice around the Gulf of St. Lawrence to the last stages of stagnation on the Labrador plateau to the north.

1.5 The Present Project

General aims

The present project seeks to provide basic regional information by determining some of the physical properties of the surficial materials and by explaining the evolution of the glacial and postglacial elements of the landscape, and to develop a model for Quaternary geomorphological research in forested areas of the Canadian Shield.

Specific objectives

The specific objectives of the project are:

(1) to determine the distribution of unconsolidated materials and display them on a map at a scale of 1:125,000.

(2) to determine the stratigraphic sequence of the deposits and interpret their genesis and history.

(3) to determine the physical and behavioural properties, and their variability, for the various deposits.

(4) to examine the glacial and postglacial evolution of the region; particularly, to determine the time of deglaciation and the extent and altitude of the postglacial marine transgression.

(5) to examine the pattern of ice retreat in the estuary, by interrelating glacial, terrestrial and marine deposits, and by correlating late-glacial events along the North Shore of the St. Lawrence estuary with events in Labrador, the St. Lawrence lowlands, and other areas bordering the Gulf of St. Lawrence.

Methods

This section indicates the kind of approach to data collection taken for this project. Specific technical details concerning some of the methods are described in the Appendices.

Air photo interpretation

Air photos were used extensively throughout the project for:

(1) a preliminary survey, which established the size of the area which should be studied. During this initial interpretation, sites that appeared to be typical of the terrain units within the region, features of special interest, and areas where interpretation was uncertain, were marked for special ground study.

(2) a field mapping base (interpretation of landforms and delineation of map-unit boundaries).

(3) the examination of inaccessible areas and those crucial to interpretation which lie beyond the study area (specifically, the heads of former fiords which once extended 50 km inland from the present coast).

(4) the measurement, using stereopairs, of dimensions and slopes of landslides which are greater than 30 m broad. Smaller slides were mapped from the ground.

Most of the coverage is 1952 NAPL photography at a scale of 1:60,000. East of Port-Cartier 1967 photos at 1:33,000 were used extensively.

Field work

A total of six months was spent in the field during the summers of 1971, 1972 and 1974. An assistant was available for about half that time. Most of the field time was spent mapping. A road survey at the beginning of the 1971 season revealed that few of the roads included on the air photos and topographic maps were usable. Since that time, however, some lumber tracks have made other areas accessible. All road exposures, cuts along the Arnaud and QNS&L railways, foundation excavations at Sept-Iles, several gravel pits, and numerous borrow pits were examined. River bank exposures were also investigated, but a boat was not used. The sediments were described in terms of colour, texture, stratification and aggregate structure, composition, shape and strength properties; qualitative interpretations were made and the stratigraphic relationships of the materials were established. Vane shear strength, penetration resistance, and soil pH and density were also determined. Three-dimensional till fabrics were measured where thick till was exposed. The orientation and sense of glacial abrasion forms were recorded. Elevations at the marine limit and on terraced sequences of raised beaches were obtained by closed altimetric traverses. A search for shells for radiocarbon dating and paleoenvironmental analysis was made at all marine sediment exposures and in deposits which were possibly under direct marine influence. Logs from boreholes and auger sites were obtained from the Iron Ore Company and Cartier Mining Company. Additional records from new bridge sites were obtained from the Ministère des Transports du Québec.

Office and laboratory work

Office and laboratory work included:

(1) the final mapping and interpretation from air photos.

(2) granulometric analysis and determination of the textural parameters of the sediments.

(3) petrographic identification of rock chips and pebbles, and mineralogical analyses of sand and clay components.

(4) determinations of water contents and Atterberg limits.

(5) bulk and dry density determination from samples of fine sand, silt,

and clay of known <u>in situ</u> volume. Attempts to obtain undisturbed samples from sandy tills were unsuccessful.

(6) identification of molluscs and the extraction of microfossils from sediment samples.

(7) interpretation of borehole data.

1.6 Acknowledgements

I am deeply indebted to Dr. Paul F. Karrow for the many helpful suggestions which permitted me to complete this thesis, and for critically reading the manuscript. I am also grateful to the Department of Geography for allowing me to transfer to Waterloo when I was part way through the Ph.D. program at another university.

The Geological Survey of Canada financed most of the field component of this research. The Departments of Geography, Carleton University and University of Waterloo, loaned additional field equipment. The Earth Sciences and Geography Departments at Waterloo provided the laboratory space and equipment necessary to carry out mineralogical, sedimentary and engineering analyses. F.J.E. Wagner and F.E. Cole, Atlantic Geoscience Centre, identified molluscs and forams. The Geological Survey provided radiocarbon dates.

Iron Ore Company of Canada generously loaned company borehole records and results from geotechnical analyses. The Ministère des Transports du Québec provided borehole data from three bridge sites.

My field assistants were Helen Dumych, Sylvia Ulmanis, and Richard Blais.

2. NATURE OF THE STUDY AREA

2.1 Geographic Extent

The area covered by this report is situated in the southern portion of Labrador-Ungava, along the north shore of the Gulf of St. Lawrence.

The area mapped for this study comprises the southern parts of the Sept-Iles and Cap Chat 1:250,000 map sheets. The area is bounded by the Moisie River ($66^{\circ}00'$W) on the east, and the Mistassini River ($68^{\circ}00'$W) on the west. Within this general area field mapping was confined to the coastal strip, generally extending inland less than 20 km. The extent of the mapping zone was determined by accessibility, by time, and by the amount of coverage needed to include the main elements of the landscape. The area selected includes accessible portions of the two major terrain types found in the North Shore district: the bedrock-dominated upland, and the coastal lowland. It includes some tundra as well as closed-forest terrain, and extends inland sufficiently to cross the marine limit and to include the heads of some fiord-like valleys.

The study area comprises the following 15-minute map sheets: 22 J 1 W½, J 2, J 3 and preliminary topographic maps 22 G 5, G 6, G 11, G 14 and G 15. Mapping was carried out at the scale of the air photos, which was about 1:60,000. The data is presented at a scale of 1:125,000.

The field area is outlined in Figure 2-1. The cities of Sept-Iles (population 33,000) and Port Cartier (population 3,730) are the main urban centres in the area. The non-incorporated settlements of Moisie, Rivière Pentecôte, Pointe aux Anglais, Baie Trinité, Godbout and Franquelin are scattered from east to west along the coast.

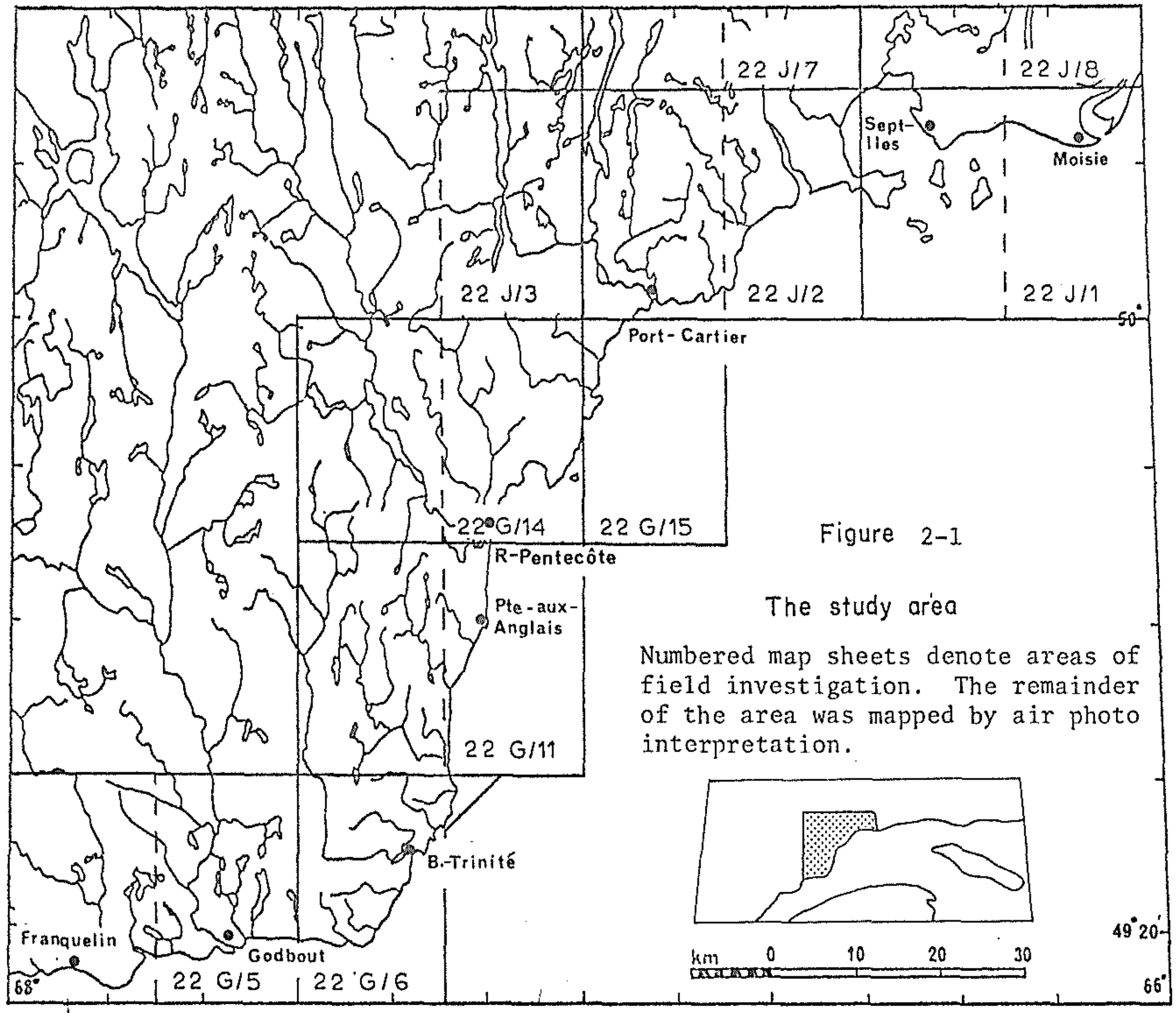


Figure 2-1

The study area

Numbered map sheets denote areas of field investigation. The remainder of the area was mapped by air photo interpretation.

The area is served by Route 138 (denoted Route 15 on maps), which runs parallel to the coast as far as Moisie. In addition, in 1973 an old road between Port-Cartier and Gagnon was repaired and reopened. Most of the tracks and older roads indicated on the topographic maps are in disrepair and are unsuited to vehicles. Inland access was therefore gained by foot traverses along these old roads and lumber tracks, as well as rights of way along the QNS&L and Arnaud railways, and the Quebec-Labrador power line. Limited traverses were also run along some of the stream channels and through the bush.

2.2 Climate, Vegetation and Soils

Climate

The area lies in the Subarctic climatic region of Koeppen (Dfc code). The mean annual air temperature is 0^{o}C. Daily means at Sept-Iles airport range between $+15^{o}$C in July and -15^{o}C in January. The freezing point is crossed 97 days per year, mostly in April and October (D.O.T. data, 1969-74), and the frost free period is 108 days (Wilson, 1971).

Precipitation averages 1,080 mm (42.4") annually, of which 430 mm of water equivalent fall as snow. The moisture is spread evenly over the year but snow builds up to 102 cm (40") on the ground and melts rapidly in the spring. Water balance calculations show that of the 1,080 mm of precipitation, 465 mm (18") are used in evapotranspiration; there is an annual water surplus of 615 mm (24").

Winds are predominantly from the north and northwest in winter, and from the east in summer. The prevailing velocity is 4.5 metres per second (10 mph).

Those aspects of the climate which directly relate to the geomorphology of the area, are as follows:

(1) The summers are sufficiently warm and humid to produce large organic accumulations, and the climate is cool enough to prevent rapid decay. The result is extensive, thick, deposits of muskeg.

(2) Extensive heaving may occur in the spring and fall in frost susceptible soils.

(3) During the snowmelt period rapid runoff produces turbulent overland flow and high stream discharge. Noncohesive materials, such as sandy till and estuarine valley fill deposits,are subject to accelerated erosion.

(4) The prevailing winds are capable of entraining loose dry sands up to two mm in diameter. Unprotected or unvegetated parts of the coastal plain are therefore subject to extensive deflation.

Vegetation

The study area, characterized by a stand of closely spaced trees, lies within the main Boreal Forest (Hare, 1950). Black spruce, balsam fir and white spruce are dominant species and paper birch is the most common hardwood associate. Aspen and jack pine are secondary species which colonize disturbed sandy areas, whereas tamarack is located near wet sites. The coniferous trees develop interlocking branches which restrict visibility on the ground, and render air photo interpretation difficult.

Peat bogs are extensive on the sand plains. Large string bogs consist of shallow pools of open water underlain by gyttja, and separated by "strings" of vegetation, largely *Sphagnum* moss with a few sedges and shrubs. They are ringed by drier areas of muskeg in which shrub clumps and stunted spruce are also present.

Except for present day tidal flats and newly-formed beach ridges which have specific plant communities, similar vegetation associations recur on all types of inorganic terrain within the field area (Sylvia Ulmanis, pers. comm.); therefore, vegetation cannot readily be used as an indicator of the substrate.

Soils

Soils in the area are classed as "non-arable" by ARDA, and they have been shown to have a low nutrient status. The predominant sub-group is the orthic humo-ferric podzol (Canada Dept. of Agriculture, 1974, p. 74), which is best developed on well-drained sandy-textured substrate. These soils apparently develop quickly, since incipient profiles with bleached horizons can be observed on backshore beach ridges along the present shore.

A bleached, siliceous, ashy white Ae horizon of the soil profile, usually less than 15 cm thick, is overlain by a mor-type humus layer of needles and twigs, and is abruptly underlain by a reddish-brown Bf horizon characteristic of podzols, which extends to a depth of about two metres. This Bf zone is commonly cemented by iron oxides; induration is best developed on well-drained sandy soils of the coastal plain, where it reaches a thickness of 60 cm. The indurated zone generally follows the contour of the land surface but it may also be present as "discontinuous vertical tongues in uncemented material" (Moore, 1973, MS). Tests by Moore (1973, MS; 1976) suggest that the cemented zones form by the release of large quantities of iron and aluminum by *in situ* weathering of the hornblende, magnetite, and ilmenite grains which are concentrated in both old and recent beach deposits. This weathering is made possible because the coniferous tree cover and resulting acid nature of the soils (pH 4-5.5) provide an active environment for the release of iron and aluminum. Moore (1973) emphasizes that the cementation may be reinforced by iron and aluminum translocation from above, but states that podzolization is not too important in the formation of the cemented horizons.

The presence of the indurated layer has altered the appearance of the landscape and affected land use as follows:

(1) On the sand terraces at Natashquan (east of the field area) the hardpan has been held responsible for poor drainage conditions and the subsequent accumulation of peat (Welsted, 1960, p. 93). This could be true for the terraces between Godbout and Moisie as well.

(2) In areas influenced by wind activity, erosion by deflation is very limited once the cemented layer is exposed.

(3) The exposed hardpan is locally important as the base for bush roads; it also forms the surface of the airstrip at Baie Trinité.

(4) Where the hardpan is particularly resistant, it could not be penetrated by hand augering. This technique was therefore used sparingly during field operations.

2.3 Drainage

The area is drained by the St. Lawrence River and its tributaries. The St. Lawrence flows in a broad trough 45 km wide at Pte des Monts, and 110 km wide opposite Sept-Iles. Basins in the estuary extend to a depth of -360 m in this area (the Cabot trough deepens to -530 m). In the western extremity of the field area the valley is steep-sided because a fault scarp forms the northern boundary of the river, but east of Pointe des Monts the valley slopes more gently from the northern coast to the central trough.

Characteristics of preglacial channels

The major elements of the drainage system within the field area are believed to have pre-Pleistocene origins (Cooke, 1929). In addition to the St. Lawrence, the Moisie and Ste-Marguerite Rivers flow in preglacial rock-walled gorges as much as 2½ km wide. One borehole in the Moisie valley indicates that the bedrock floor lies more than 200 m below sea level, beneath 240 m of glacial and estuarine sediment (Table 4-1, p. 84). In postglacial time, underfit rivers have created a series of terraces within the larger valleys as they incised unconsolidated material which once filled the valleys to an elevation of about 130 m. These underfit streams are nevertheless among the largest rivers in the area. Discharge for the Moisie, for example, is about 15,000 cfs for normal summer flow and 50,000 cfs during snowmelt periods. The rivers flow off the upland and through the coastal plain without any marked change in gradient, but shallow nickpoints and rapids in the long profile of the Moisie were mapped by the Commission des Eaux Courantes du Québec (1951). The reason for the nickpoints is not apparent, but they might be related either to the glacial history or to rock type and structure. On Rivière Pentecôte the presence of two waterfalls along the lower reaches suggests that some stretches of the present river are not flowing within the over-deepened preglacial channel.

The general configuration of these largest channels appears to be structurally controlled, although river paths are not always directly related to large-scale structure as seen on ERTS imagery, and Cooke (1929) claims that parts of the drainage pattern are related to, and inherited from, structures in the Paleozoic rocks which once covered the area. Furthermore, some parts of the original networks have been disrupted by glacial and estuarine debris; for example, Daigle Creek flows northward in an outwash-choked channel to join the Moisie River, whereas the original "Daigle" river was a southward flowing stream in the preglacial Moisie system. Outwash fillings also act as drainage divides within channels of the Godbout and Trinité Rivers, creating local flow reversals. Presumably, once headward erosion is sufficient, the outwash plugs will be breached and the streams will revert to former southerly flow directions.

The valleys of Rivière aux Rochers Nord and Rivière Pentecôte are also relatively large and have portions which may predate the last glaciation. These, together with the smaller Mistassini, Franquelin and Petite Trinité river valleys have acted as major meltwater channels during glacial retreat.

Recent river profiles

Where younger rivers which originate within the field area, such as Rivière aux Rochers Sud and Rivière des Rapides, flow across the coastal plain, they occupy shallow channels cut into bedrock. Water drains southward in a stepped profile over a series of waterfalls and rapids. The rivers overflow their channels during snowmelt or heavy rains, and extensive flooding occurs in the lower reaches.

Small streams on the upland and sandy coastal plain

Some of the smallest streams on the uplands are adjusted to local structures but many have no well-defined valley. The small scale drainage network is non-integrated; water collects in numerous depressions and spills over from one to another through low areas or poorly-defined channels. Streams originating on the coastal plain also tend to be deranged. In sandy areas water escapes by direct infiltration or is absorbed by organic deposits. Surface drainage over organic terrain is generally restricted to a disconnected lattice of ponds and runnels which allows some of the water to flow outwards from topographic centres to moats which mark the bog peripheries.

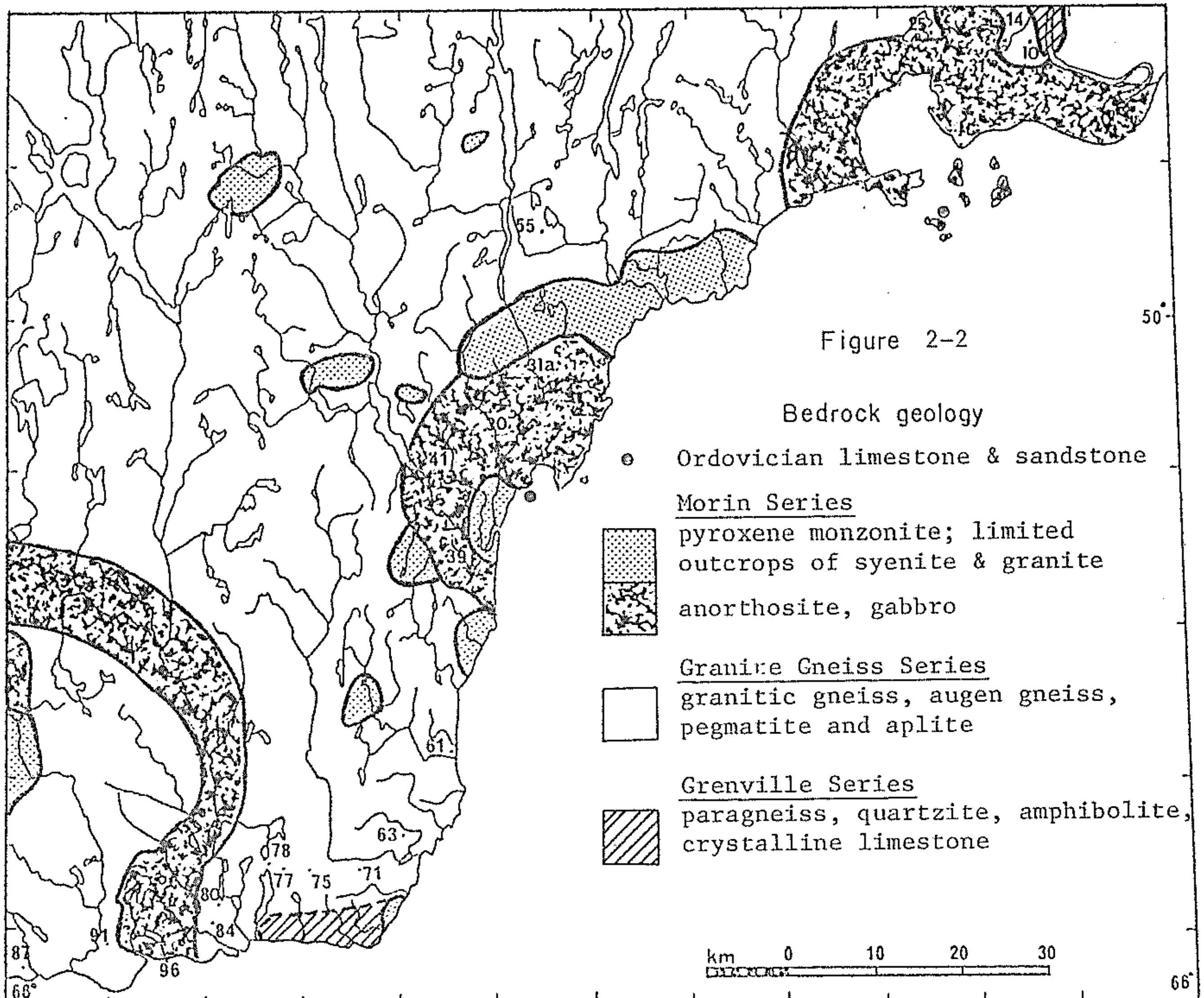
2.4 Bedrock Geology

Principal lithologies

The principal lithologies of the coastal zone have been described by Faessler (1942 a, 1945). Since that time Moyer (1959) has undertaken more detailed work in the Lac Vermette area southeast of Lac Walker. The following summary and accompanying map (Figure 2-2) are based on their observations and chronology, and on a published map from the Ministère des Richesses Naturelles du Québec (n.d.).

The oldest rocks belong to the Grenville "Series" comprising para-gneiss, amphibolite and crystalline limestone. These are located in a strip along the Moisie River and along the coast between Godbout and Baie Trinité.

The Grenville rocks have been altered to medium to coarse-textured granitic gneisses, which cover most of the area. Augen structures are commonly encountered where these rocks are found in association with ultrabasic intrusions. The syenite and pegmatite which outcrop at Pte Jambon have also been grouped into this granite-gneiss "series".



Sources: Faessler, 1942 and 1945; La carte géologique du Québec

The latest major intrusion is the Morin Series, characterized by gabbro (locally with titano-magnetite) and grey-green anorthosite, but also including fairly extensive areas of pyroxene monzonite. These rocks are located between the gneisses and the St. Lawrence River, and form the coastline between Rivière Pentecôte and Rivière Moisie. Post-Morin diabase dykes are found among the Morin rocks, generally where they form low outcrops along the coast.

Knowledge of the distribution of these principal rock types theoretically permits local till provenance to be determined, since the granite-gneiss series consists of acid rocks rich in quartz, hornblende, and orthoclase, while the Morin Series consists primarily of basic rocks having large quantities of pyroxene, olivine, and plagioclase feldspar. Field checks suggest, however, that care must be exercised in using the bedrock maps for provenance work, since much of the area mapped as granite gneiss is actually quartz granulite, while the rims of the gabbroic intrusions are pyroxene granulites, having substantial quantities of quartz.

Paleozoic limestone is reported in two small outliers along the coast: one at Caye à Chaux offshore from Sept-Iles, the other at Pte Carrière five kilometres east of Pentecôte village. Both areas are very small.

Nature of bedrock outcrops

Bedrock crops out, or directly underlies a thin veneer of till over most of the area. The overall appearance of the rock is quite fresh and surfaces show signs of being abraded by glacier activity. Grooves, chattermarks and plucked faces are found on coarse-textured rocks; striae and polished surfaces are present on finer-grained material.

The granitic rocks are virtually unweathered, but arabesque corrosion patterns about one millimetre deep were observed underneath moss mats. Faessler (1945 p. 9) reported one occurrence of disintegrated bedrock near Lac Daigle. He described this as a sand composed of grains of hornblende, chlorite and mica mixed with larger fragments of amphibolite.

The gabbroic rocks are also generally weather-resistant or show only slight weathering. Some of the joints, which may have widened by freeze-thaw activity or by postglacial tensional stresses, are oxidized, but weathering seldom extends farther than one millimetre in from joint surfaces.

An isolated pocket of disintegrated anorthositic bedrock (Figure 2-4) was located at Lac Caché, west of the Ste - Marguerite River and a more extensive area was found between Lac Pentecôte and Riv. Vachon. Chemical weathering has proceeded inwards from a well developed rectangular joint system, leaving the central cores of the joint blocks relatively sound. The rock appears to be structurally intact but it crumbles into sharp pebble-sized fragments of plagioclase and a loose mass of silty red-brown material when it is disturbed. Carbonate analysis of the fines reveals a very small quantity of calcite in the weathered material.

2.5 Physiography

The area is part of the Laurentian Highland Division of the Canadian Shield (Bostock, 1970), which closely corresponds to the Grenville geological province of Stockwell (1963). The land can be further subdivided into two distinct units: an upland and a coastal plain.

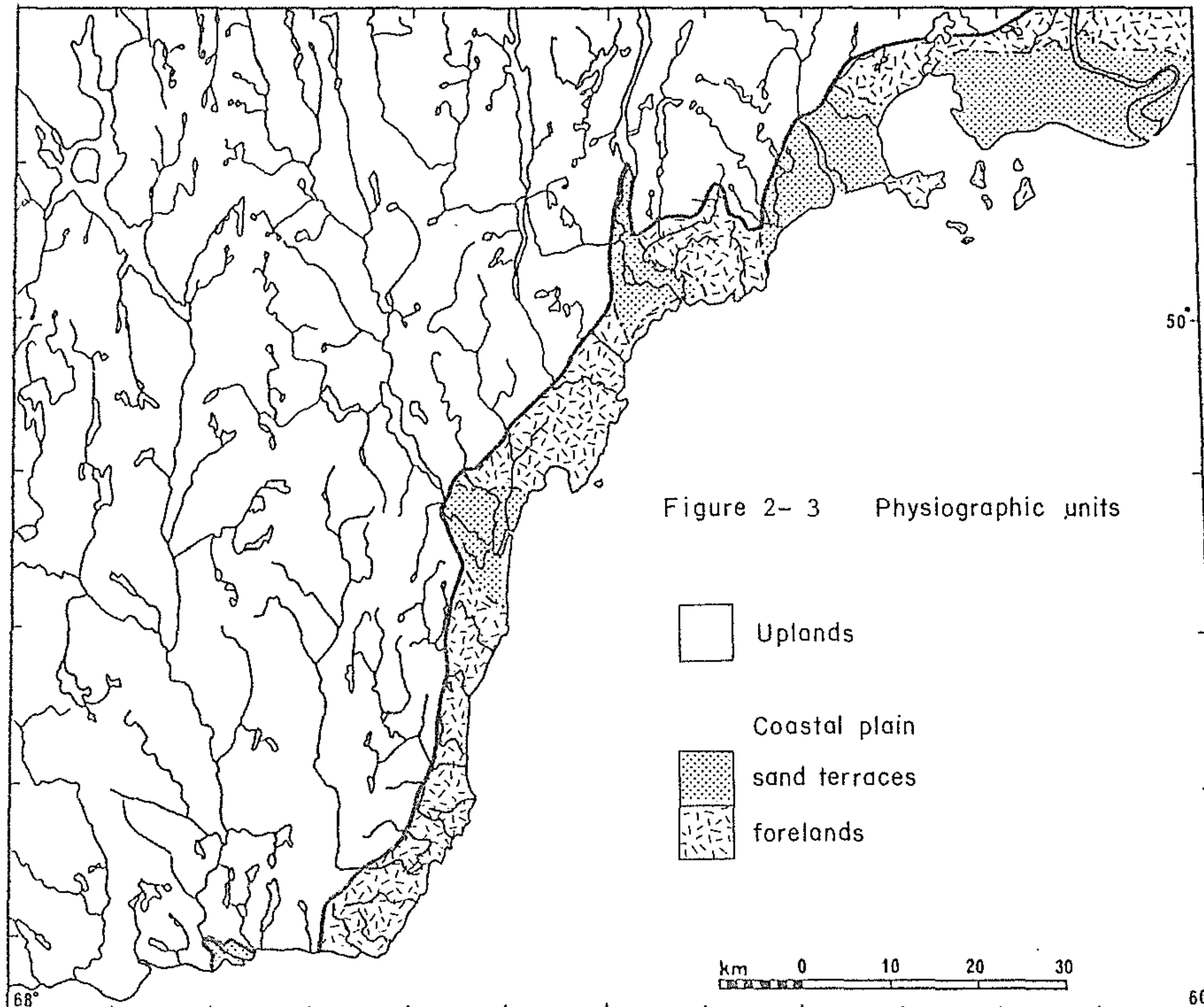


Figure 2- 3 Physiographic units

Upland

Topography of the bedrock

The upland, part of the southward sloping Laurentide Massif described by Hare (1959), constitutes the major portion of the map area. The landscape is bedrock-dominated and is characteristically a succession of rounded rock hills (Figure 2-5); both drainage and land form are structurally controlled. The highest elevation within the field area is 720 m and is located about eight kilometres northwest of Lac Pentecôte. Local relief is generally on the order of 15 to 30 m, although where streams from the interior trench across the massif, local relief exceeds 300 m (e.g. near Lac Walker) (Figure 2-6).

Principal glacial features

There are few signs of intense glaciation. Large scale abrasion forms such as U-shaped valleys and drumlinized terrain are present but widely scattered. Both Hare (1959) and Hogan (1971), who mapped the bedrock of the area to the north, have noted the general absence of large end or interlobate moraines such as the Highland Front system in southern Quebec and the moraines of Southern Ontario. Nevertheless, several morainic systems were mapped within the field area. The largest and most continuous is a prominant, double-crested ridge near Lac Daigle. Other discontinuous ridges are located along valley fronts between Rivière Riverin and Rivière Vachon in the central part of the map area. A series of ridges, 15 to 30 km inland, trend northeast-southwest for about 60 km across the Cap Chat map sheet between Lac Dionne and Lac Pentecôte and continue westwards into the Manicouagan Valley. A series of minor ridges, situated in the Baie Trinité area, extends across part of the upland and onto the adjacent coastal plain. The remainder of the upland is bare or

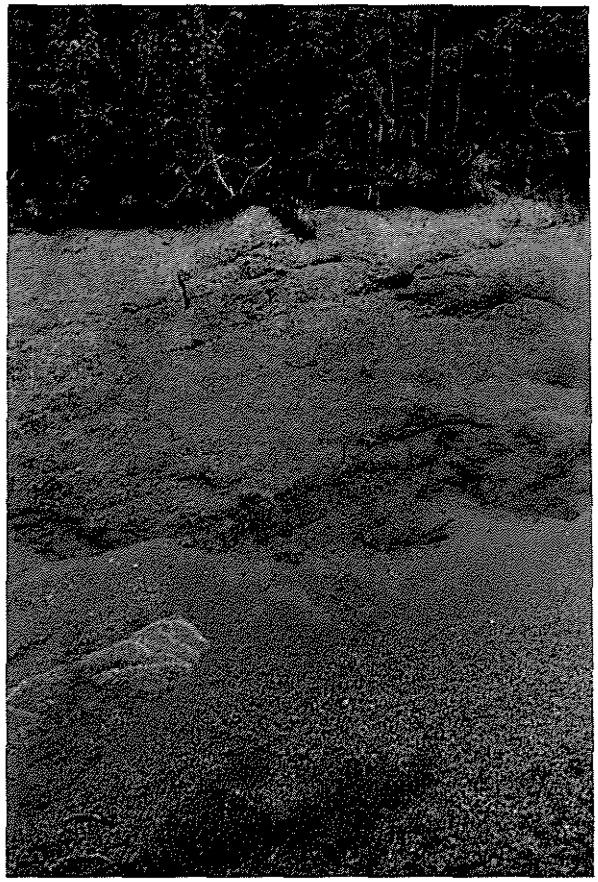


Figure 2-4 Four-metre section of disintegrated anorthosite at Lac Caché. The joint system is well developed.

Figure 2-5 Rolling topography of the uplands. Bedrock is characteristically at, or near the surface. Photo taken near Ste-Marguerite River.

mantled by a thin veneer of till. As previously mentioned, surficial features contribute only minor topographical detail to the bedrock-dominated upland.

Coastal plain

Foreland transition zone

The southern edge of the upland appears to be a fault scarp. Over much of its length it terminates abruptly at the coastal plain or, in the west, in the St. Lawrence Valley, creating an abrupt coastal cliff about 80 m in height. However, the central part consists of a set of en-echelon faults which produces a low rocky foreland extending into the St. Lawrence. Below the marine limit this foreland has been wave washed or covered with marine sediments.

Sand plains and their landforms

Sand plains constitute the second major physiographic unit of the coastal plain. Faessler (1942 a) has named this unit the Champlain Plain, but the area is beyond the zone of the Champlain Sea. It consists mainly of aprons of elevated estuarine and deltaic sediment, chiefly clay and silt, overlain by littoral sand. These aprons, which are associated with major outwash channels within the Upland, coalesce to form extensive sandy lowlands, the largestof which extends for 55 km between Pte Jambon and the Moisie River. Terraces rise from sea level to about 90 m ASL except at Sept-Iles where a flight of prograding beach ridges extends to 130 m. Except where Rivières Pentecôte and Moisie have incised the sediments, the local relief is very low (Figure 2-7); the major landforms are dunes, river terraces, beach ridges, and wave-cut terraces

Figure 2-6 Deep, preglacial, steep-sided valleys which dissect the upland. Photo taken at the outlet of Lac Walker, looking north.

Figure 2-7 The coastal plain, viewed from the scarp edge of the upland west of Ste-Marguerite River.

which mark positions of former sea levels. Fields of aeolian dunes are located west of Baie-Trinité, and between Sept-Iles and Moisie. Raised beach ridges are widely distributed but ridge sequences are neither continuous nor at consistent elevations throughout the area. Beach and river scarps are associated with all major delta deposits, specifically those near Godbout, Baie-Trinité, Pentecôte, Port-Cartier, Ste- Marguerite and Moisie River. Between the ridges and scarps are extensive flat areas covered with peat bogs.

The remaining landforms in the area are the boulder-strewn tidal flats near Sept-Iles, Mistassini, and Baie St.-Nicholas, and the boulder barriers which also extend along the coast from Pentecôte to Baie-Trinité.

3. SURFICIAL MATERIALS PART A: GLACIAL DEPOSITS

3.1 General Statement

Unconsolidated materials in the field area belong to the youngest glacial events, the marine episode which accompanied the last stages of glaciation, and the postglacial period. The sequence of deposition and the main characteristics of the sediments are summarized in Table 3-1 and are described in the following section.

3.2 Till

Stratigraphic position and continuity

There is no stratigraphic evidence for more than one till sheet in the area, nor any major textural changes or oxidation layers below the modern soil profile which would indicate the presence of more than one till.

On the upland, till directly overlies bedrock and forms the surface material, either as ground moraine or as morainic ridges.

Below the marine limit outcrops of till are infrequent. In a railway cut 500 m east of Rivière des Rapides, however, a small pocket of till is exposed (laterally) between bedrock and banded marine clays. This exposure indicates that the upland till sheet continues beneath the marine deposits and is present, or was present, beyond the area where it is now exposed at the surface. Presumably then, this exposure also suggests that the formation of till on the upland generally predates the marine episode.

Reworked till is exposed where bedrock lies near the surface below the marine limit, and it is visible in road cuts south of Lac Hall (22 J 7)

Table 3-1 Table of Formations

Era	Period	Subdivision	UNIT	DESCRIPTION
CENOZOIC	QUATERNARY			
	Late Wisconsinan			
		Postglacial	Organics	String bog and bog meadows consisting of fibrous peat; minor amounts of muck.
		Postglacial	Alluvium	River transported sand and gravel forming terraces or channel bars; varied textures, forms, and structures.
		Postglacial	Eolian Sand	Well-sorted, stratified, medium to fine sand in parabolic ridges or rounded hillocks.
		Marine	Littoral Sand (minor clay)	Well-sorted, sub-horizontally stratifed medium to coarse brown sand / Boulder ramparts / Tidal flat clays.
		Marine	Nearshore Deltaic Sand	Medium-fine sand with tangential trough and festooned current structures.
				Fine sand with ripple-drift structures in planar delta sets.
				Interbeds of banded clay and fine, grey, stratified sand.
		Marine	Offshore Marine Clay	Sub-horizontally bedded, banded silt and clay.
				Massive, poorly sorted, grey clay.
		Glacial	Outwash and Ice-contact Gravel	Poorly-sorted, coarse, current-worked gravel grading to poorly stratified sand.
		Glacial	Till	Grey-brown, sandy, poorly sorted granitic till.
PALEOZOIC	ORDOVICIAN			
			Caye-à-Chaux Limestone	Limestone bearing Trenton fossils.
PRECAMBRIAN	PROTEROZOIC			
			Morin Series	Intrusive gabbro and anorthosite.
			Granite Gneiss Series	Red granite gneiss and pegmatite.
			Grenville Series	Metasedimentary rocks, chiefly banded paragneiss and amphibolite.

and along the coast between Lac du Portage and Godbout (22 G 5). With the exception of the lower left bank of Petite Rivière de la Trintié at its mouth, and at one location $3\frac{1}{2}$ km upstream, till was not seen exposed along river banks. (The large river valleys are infilled with estuarine material to depths below present sea level.)

There are no borehole records in which till is positively identified, although it may be present beneath Sept-Iles where pockets of "gravel" were reported in depressions in the bedrock under about 50 m of massive clay and sand; in boreholes which touched bedrock knobs there was no trace of this "gravel". Similarly in the few boreholes along the QNS&L railway, "gravel" was found to underlie marine sands. This could be either till or outwash. The remaining boreholes that exceeded 15 m depth terminated at "refusal", which could be bedrock, gravel, till, or a boulder in marine clay.

Morphological expression of the till

(a) Ground moraine

1. General nature

Till on the upland forms a discontinuous, featureless blanket, varying from zero to at least six metres in thickness. Thick till was noted in two areas; one north of Sept-Iles, and another, extending north-northeast to south-southwest, west of Baie Trinité. In most places till is commonly less than two metres thick and has therefore been mapped as till veneer overlying bedrock (unit 2b). As the till thins, the cover becomes discontinuous; for example, not far from a major exposure near Lac Dupont festoons of till about one metre wide and 10 cm deep extend across bare rock bosses. The long dimension of these linear deposits is perpendicular to the direction of ice flow as indicated by plucking and grooving. Between Clarke City and Port Cartier stretches of bedrock are completely devoid of overburden.

2. Reworked subfacies

Reworked till (map unit 2d) is present in the field area below marine limit, and forms a textural subfacies of till. The reworked till has the general morphological appearance of the more widespread units, 2a and 2b, except at the Baie Trinité dump, where it appears as irregular mounds protruding above the flat sand terrace. Wave action, and in some cases river currents, have altered the diamictic character of the till by rearranging or removing the matrix. Reworked tills can be recognized in the field by their clean appearance because the pebbles and sand particles do not have clay skins. They are further recognized by their altered texture and composition: during the reworking process the original sedimentary structures were altered, and small grains of light minerals were removed. The extent of alteration depends on the exposure and type of reworking. Generally the material at the lowest elevations has undergone the most extensive alteration. Specific examples of textural changes are documented in the later section on texture and structure.

(b) Morainic ridges

Several sets of small ice-contact ridges are visible on air photos of the area. Those near the coast were field-checked but the ridges fartherinland were mapped by air photos alone; since the moraines are fairly small and much of the area is heavily wooded, some ridges additional to those which appear on the map might have been missed. The larger ridges in the field area are assumed to be end moraines. A series of smaller ridges - the Baie Trinité minor moraines - does not

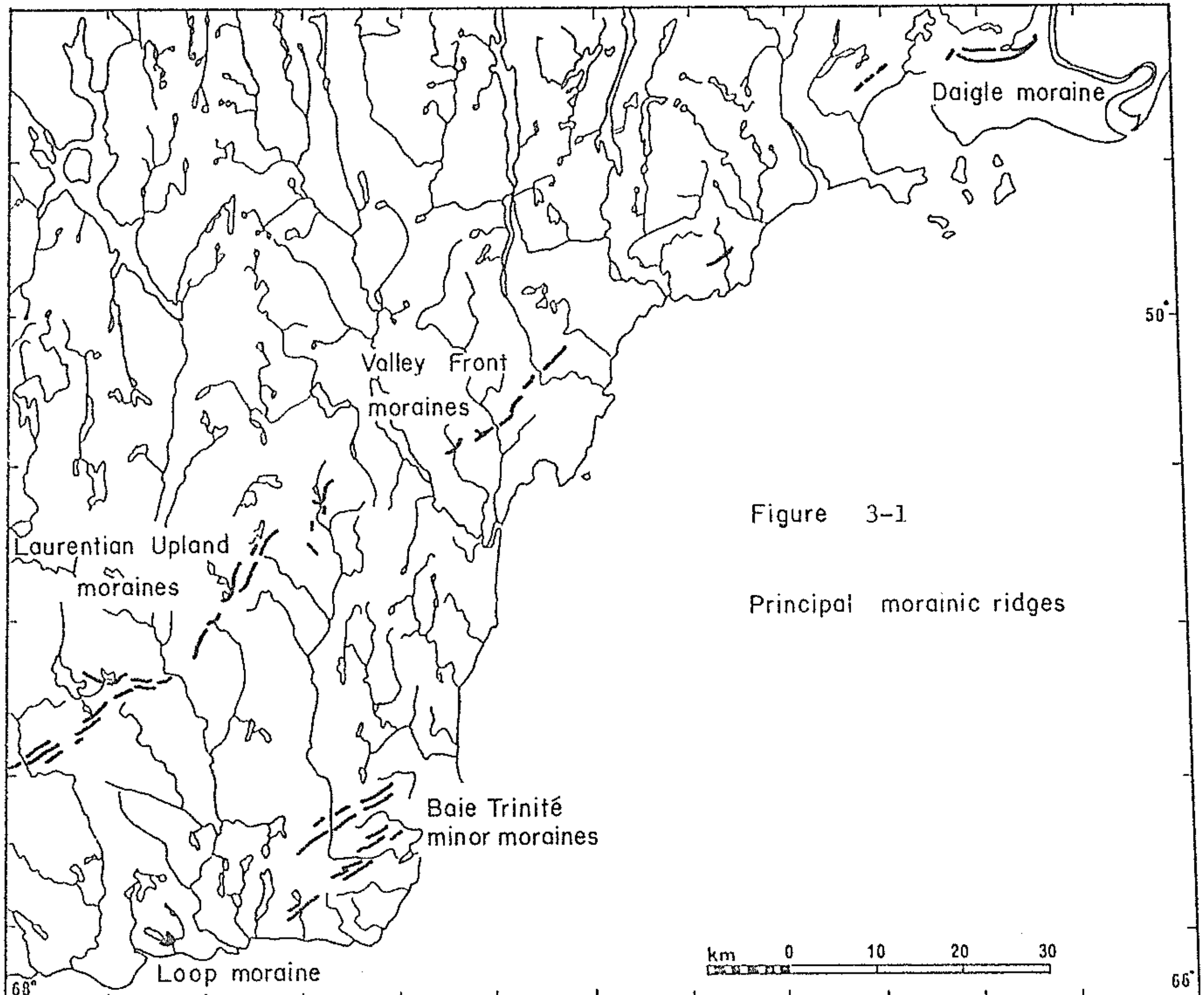


Figure 3-1

Principal morainic ridges

necessarily mark a sequence of ice marginal positions.

1. Daigle moraine

The Daigle moraine, with a length of 12 km and a maximum width of 200 m is the largest till ridge found in the study area. It is situated directly above the marine limit on a rocky foreland about 10 km northeast of Sept-Iles; a large outwash plain splays out in front of the ridge, while bedrock and ground moraine lie on its proximal side. In plan, the moraine consists of two broadly arcuate subparallel ridges with a hummocky boulder-strewn area between the ridge crests. The highest point is 150 m ASL and maximum relief between ridges and the surrounding area is 20 m. The distal slopes are well defined, convex, and are inclined at about 18°. The eastern and western extremities are also abrupt, terminating in a peat bog near Rivière Moisie and on a sand plain, respectively. The general trend of the moraine is N 70°E (perpendicular to the direction of striae at Rivière des Rapides, which have bearings N 20°W to N 30°W), but it is slightly lobate to the south. A small limb at the western extremity is oriented northeast-southwest and it is separated from the main ridges by a small re-rentrant or water gap. The ridge crests are interrupted by a water gap at Lac Daigle, where oucwash from the Daigle channel to the north broke through and spread out to form an outwash plain. This event affected the nature of the till surface near the water gap, as outwash was impounded for a short time before the moraine was breached. As a result, the sides of the ridges around Lac Daigle are slightly terraced, there is some current bedded gravel on the distal slopes of the southern ridges, and along the breached zone the till has been restructured. Stratified layers of sand and gravel have been plastered onto, and around, large boulders by high velocity river currents.

The nature of the till, and the configuration and elevation of the moraine suggest that the glacier was land-based when the moraine was formed.

2. Valley front moraines

A ridge of till is situated five to seven kilometres inland from the coast between Rivière Pentecôte and Rivière aux Rochers. The ridge is low and discontinuous on high ground but widens and thickens where it crosses the fronts of river valleys.

South of Lac Dupont, and forming the southern border of the lake, are rounded hillocks of till. These mounds create a relief of about 15 m on the distal side, and parts of the proximal side where they abut the lake. In other places they grade to thinner till cover. Two other extensive deposits are located where the Riverin and Vachon River Valleys leave the bedrock forelands. The ridges there consist of mounds of till which extend across the valleys, a distance of two to three kilometres. Relief is about 20 m at Riverin and the lowest elevation of exposure of the moraines is at 115 to 120 m (the marine limit).

No lateral moraines were found in these valleys. The string of morainic deposits is oriented perpendicular to general ice flow directions. Because of these distributional characteristics, the moraine is interpreted as marking the former position of the general ice front rather than as a series of moraines formed by late ice tongues in the valleys. The difference in size between the valley parts of the moraine and the contiguous upland ridge could be due to the greater abundance of available debris in valleys, differences in glacial mechanics operating in confined valleys, and probably to a lesser extent, to intensive postglacial sub-aerial erosion in exposed upland localities.

3. Shelter Bay extension

A short isolated ridge located 7½ km east-northeast of Port Cartier, at an elevation of 80 to 90 m, appears on the air photographs. Field mapping, however, revealed that although the ridge is sprinkled with boulders which are probably till remnants, the western half is a small bedrock bench partly masked by pocket beaches. The eastern part of the ridge was not investigated, but may consist of unconsolidated material, possibly till, since no rapids are visible on the air photographs where a small stream has cut through the ridge.

4. Laurentian Upland moraines

A morainic belt can be traced across the 1:60,000 air photos from the western edge of the map area at 49°30'N, northeasterly to a latitude of 49°46'N. The belt is roughly aligned with the valley front moraines farther east. Those moraines southwest of Lac Dionne extend into the end moraine near Manic 2 reported by Sauvé and LaSalle (1968). On the photos they appear as a series of small, sinuous, discontinuous ridges crossing terrain varying in elevation from 260 to 520 m. The ridges tend to lobe southwards in valleys, creating dammed lakes on their northerly sides, but gaps occur in these lobed ridges where they are interrupted by Rivières Godbout, Franquelin, and Grande Trinité, which were major outwash channels.

5. Loop moraine

A small end moraine has been mapped at the front of an unnamed valley seven kilometres west of Godbout. The horseshoe-shaped moraine partially surrounds and impounds a lake. The till ridge extends back along the valley for several hundred metres and its deposition is therefore attributed to a small outlet glacier.

6. Baie Trinité minor moraines

Portions of a set of small linear ridges cross Route 15 west of Baie Trinité. These ridges are oriented approximately northeast-southwest and have a local relief of about five metres with a spacing of about 300 m. The ridges are at an elevation of 100 to 130 m; thus, parts were totally inundated by the sea at one time. Crests and sideslopes are smooth and broadly rounded, and washed boulders lie on the surface. One of the ridges is composed of well-sorted sand (sample 74-73) covering a central rock core, but undisturbed cores of the other ridges are composed of till similar in texture to the nearby ground moraine. Near the surface, reworked parts are less compact and slightly finer than the material below; in other places, wave action has removed some of the fines. At the lower outer edges of the ridges wave activity has produced bedded sand and granule wedges around boulders. Neither marine shells nor microfauna were found within the till ridges. The significance of these ridges has not been firmly established but some possible explanations will be discussed in section 6.3.

Texture and structure

(a) Descriptions of two typical exposures

Although the overall appearance of the till is similar throughout the area, the colour, texture and mineralogy vary with changes in underlying bedrock. The following two descriptions summarize characteristics of the ground moraine at sites which demonstrate the general nature and amount of variation present in the tills above the marine limit.

The first section is located along a side road 2½ km west of the Mile 12 tunnel of the QNS&L RR. (Figure 3-2). The ground surface, which has an altitude of 131 m, is fairly flat and vegetated with black spruce forest and Sphagnum bog. A section five metres deep consists of till underlain by granite gneiss, the most extensive rock type in the field area.

The upper 70 cm of the exposure is a partially cemented layer of cobbles in a sandy matrix, oxidized to a pale brown colour (10YR 6/3). The remaining four metres of the till, where freshly exposed, is olive grey (5Y 6/2), which is the colour characteristic of all unoxidized till in the area derived from granitic source areas. The soil-water is slightly acid, and pH ranges from five to six. Irregularly-shaped and faceted boulders up to 3½ m in diameter occupy about five per cent of the exposure by area. The pebble fraction consists mainly of sub-rounded clasts of pink and grey granite gneiss, the principal bedrock lithology in the area, but some biotite schist pebbles are also present. The schist pebbles are subangular to angular because they have split readily parallel to schistosity. The matrix is very sandy. Granulometric analyses of the -4 mm fraction from three samples at this site average six per cent granules (range: 4-8%), 87% sand (range: 86-88%) and seven per cent silt-clay (range: 6-10%). Of the fines, most is coarse silt which coats the larger clasts. The material is "poorly sorted", (King, 1966), the standard deviation being 1.6 ϕ units. Three-dimensional pebble fabrics indicate that there is no strongly preferred orientation, and that the orientation of pebbles is only generally parallel to ice flow directions indicated by striae and chattermarks.

In its natural state the soil is moderately dense to dense, the

Figure 3-2 Exposure at Mile 12 showing a section of bouldery sandy till characteristic of the North Shore. Map unit 2a.

Figure 3-3 The Lac Dupont section. Map unit 2a.

penetration resistance ranging from 2.3 to 6.0 km/cm^2 (average: 4.0 kg/cm^2). The soil is well drained and natural summer water contents vary from three per cent to six per cent of the dry soil weight. The -63 micron fraction was subjected to Atterberg tests but the material did not behave plastically at any water content.

The second exposure is a two-metre section along a lumber road in the spruce forest between Lac Dupont and Lac Pentecôte, at an elevation of 135 m (Figure 3-3). The subjacent anorthosite bedrock is undulating to hummocky, with a relief greater than in the Mile 12 area. The till is generally similar to the Mile 12 material, including soil pH and water content, but the colour is pale to rusty brown (10YR 6/3), a reflection of the lithology of the till and underlying bedrock. Boulders in the till are abraded anorthosites; the maximum measured diameter is 70 cm. Pebbles are dominantly granitic but there is also a substantial component with gabbroic or anorthositic lithologies. Seventy-two per cent of the pebbles were classed in the subround-subangular category; the others, mainly cleavage fragments of plagioclase, were angular. The matrix is sandy but noticeably softer and looser than at Mile 12. Based on four samples, the matrix consists of 14% granules (range: 11-23%), 78% sand (range: 74-82%) and 8% silt-clay (range: 3-12%). Till fabrics show a strong orientation N 60°E with a westerly dip; however, the orientation of bedrock abrasion forms is northwest and north-northwest.

(b) Granulometric characteristics of the till matrix

The till of the map area consists of pebbles, cobbles and boulders in a very sandy matrix. Pebbles and larger particles occupy from 20% to 25% of the till (by exposed area). Most large clasts are subrounded to subangular; faceted pebbles are fairly common but pentagonal pebbles, as described by Flint (1971) are infrequent. Boulders are locally-derived, chattermarked joint blocks, angular to subangular except where they have been reworked and abraded by wave action.

The accompanying charts and graphs (Figure 3-4 and Appendix D) illustrate the granulometric composition of the -4 mm fraction of 76 till samples collected throughout the area, and the extent of the textural variation. Sand-sized particles account for more than 70% of the weight. About 20% of the matrix is in the granule size range; the remaining 10% is predominately coarse silt, but where tills have been water-sorted, the fines account for less than five per cent.

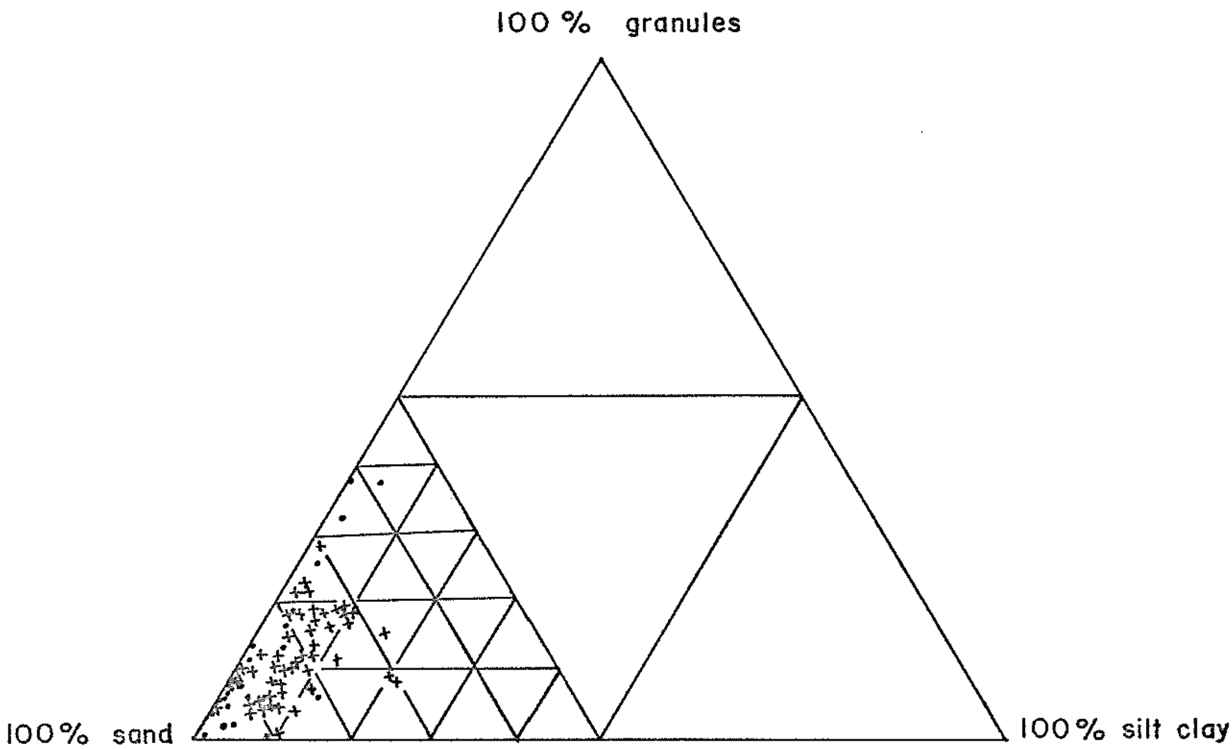
The tills are poorly sorted, the standard deviation being 1.6 phi (Ø) units. The mean grain size is 1.2 Ø (0.4 mm) and the modal class of the matrix is also in the 1-2 Ø range (0.5-0.25 mm). The particles in this range are individual mineral grains. Comminution does not appear to have been sufficient to reduce these grains to their "terminal grade" (2 to 5 Ø), as defined by Dreimanis and Vagners (1971).

In the gabbroic tills a second mode in the -3 to -4 Ø range (8-16 mm) is sometimes present, consisting of small rock fragments that have not been crushed. The frequency distributions of unaltered till are generally unskewed (average skewness = +0.04). However, when reworking has occurred and fines have been removed, the samples may have a slight negative skewness (maximum = -0.27). The kurtosis is generally near 1.0 (normal peakedness).

(c) Sedimentary structures

Although at first glance the till is diamictic, closer examination shows that indistinct, discontinuous bedding structures are present (Figure 3-5). Small cross beds, wavy laminae and lenses of sorted

Figure 3-4 Till, textural characteristics



× above marine limit , below marine limit •

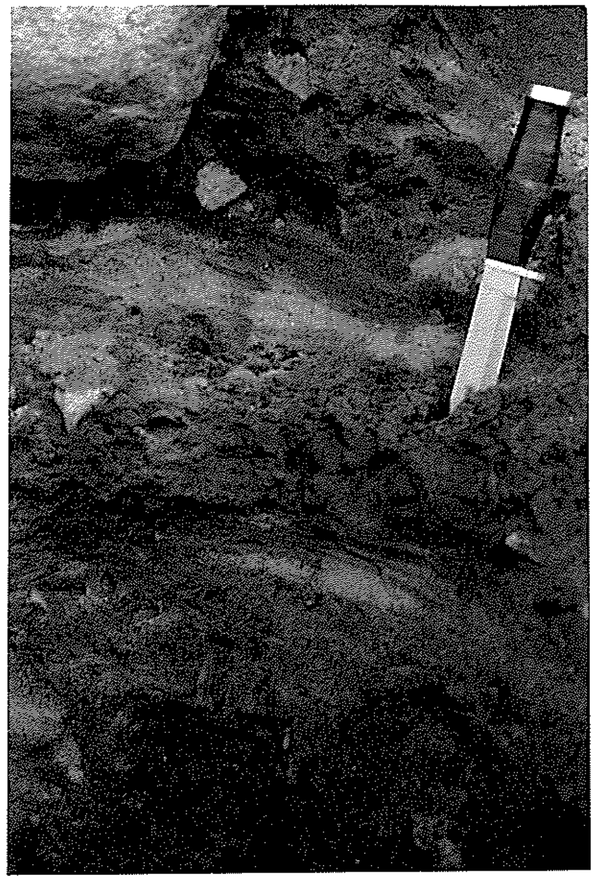


Figure 3-5 Close-up of till at Mile 12 showing bedding structure.

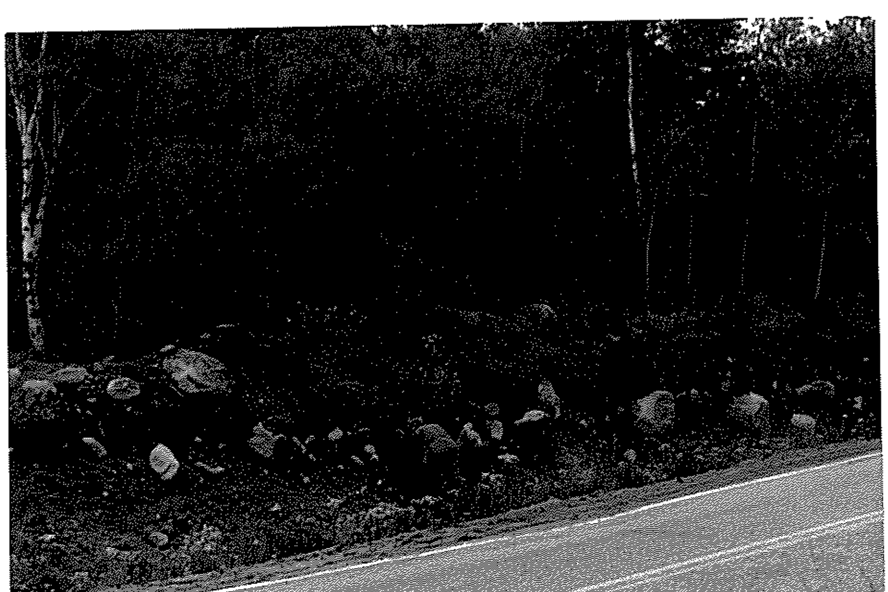


Figure 3-6 Reworked till at the minor moraines near Baie Trinité. There has been some removal of fine-grained material and reworking of the surface. Note lag boulders at top of exposure.

sediment are visible even in tills which supposedly have not undergone reworking by coastal processes. It was originally hypothesized that the material might therefore be ablation till and that the structures were the result of meltwater washing. The structures, however, are found even at the base of exposures where basal till should occur in at least some places, and in areas where mineral data (very local provenance) suggest basal transport.

As pebbles were being extracted for fabric analysis, it was observed that their orientation was tangential to, and related to the shape and position of cobbles and boulders. Both the fabric and small scale current structures suggest that differential flow occurs around even fairly small obstacles in the till. A similar alignment of particles was observed in till microfabrics by Sitler and Chapman (1955), who attributedorientation (microfoliation) to intergranular movement, by rotation and packing, resulting from the load of overlying ice. In the present area this process was probably further facilitated by an abundance of interstitial water. Depositional or post-depositional interparticle movement is also suggested by the distribution of silts, which coat both the sand-sized particles and larger clasts.

(d) Vertical textural changes

Vertical changes in texture and structure have been noted at several sites. On the crest of the northern ridge at Lac Daigle (samples 74-13 and 74-16), for example, the upper metre of material is coarser than the underlying till (mean = 0.87 $\emptyset$ vs. mean = 1.27 $\emptyset$), and better sorted (σ = 1.56 vs. σ = 1.72). Similar variations occur at Mile 12 (samples 69-28, 29) and at Lac Pierre (samples 72-2, 3). It is difficult to determine whether this upper material is ablation till or not, because in each case it coincides with the present upper soil horizons, which are subject to leaching and subaerial erosion. For the Daigle site, at least, the gabbroic pebble lithology suggests that the source of the till is very local, and that it is therefore basal till.

(e) The effect of reworking

Reworked deposits are recognized in the field by the generally clean appearance due to the removal of silty skins from the pebbles, by beach or fluvial bedding, and sometimes by lag concentrations of cobbles and boulders. There is also a concentration of heavy minerals, created when small light particles are selectively flushed out. The textural index parameters of the matrix are altered, as percentage of silt-clay decreases and the mean size increases. The standard deviation decreases as waves sort and redistribute material, and skewness tends to the negative when the fine tail of the frequency distribution is removed.

The extent of alteration depends on exposure and type of reworking. Generally, material at the lowest elevation has undergone the most extensive visible reworking. The following examples illustrate the various degrees of reworking within the field area.

1. In some areas, such as the higher parts of the minor moraines (Figure 3-6), which are very near the marine limit, reworking is limited to slight, non-systematic alteration of the upper metre, and to the presence of a lag of chattermarked erratics on the surface. At the eastern end of the ridges, however, which are at a slightly lower elevation, reworking is more extensive, and thinly-bedded sands alternating with sand and gravel layers (samples 72-39 and 74-69 in Appendix D) are visible in roadcuts. The material is coarser than average till.

2. Between Godbout and the western limit of the field area, many

road exposures are below the marine limit (100 m). The entire vertical extent of the till cover is noticeably clean and free of fines (e.g. samples 72-5, 18, 19; 74-86) and the cumulative curves show that they are better sorted than till above marine limit (e.g. samples 72-21, 33; 74-74, 77).

3. The shallow cover of till which is exposed on rocky forelands between Baie des Sept-Iles and Lac Hall also shows signs of reworking. Part of the matrix has been removed so that in the upper 90 cm of the till pebbles and rounded cobbles are in contact with each other. Oblate pebbles are oriented and slightly imbricated southwards along the most probable direction of fetch, which suggests that the re-orientation of the pebbles was a response to the force of oncoming waves.

4. An example of intense reworking is found in excavations at the Baie Trinité dump (elevation about 15 m; matrix sample 74-63) where a four-metre exposure consists of a coarse open-work boulder gravel (Figure 3-7). At this site, the coarse remnants of the matrix occupy the interstices.

5. The most extensive reworking is visible along the lower reaches of Grande Rivière de la Trinité, Petite Rivière de la Trinité (Figure 3-8) and Ruisseau Vachon west of Port Cartier. These streams have stretches of rapids in their lower reaches, created by boulder barriers in the bed, rather than by bedrock obstructions. Since the river channels are cut into old offshore and nearshore fine-grained deposits, these rapids have been interpreted as bouldery lag remnants of highly reworked ridges of till.

(f) Properties related to texture

Problems encountered in density sampling and penetration tests are

Figure 3-7 Washed till at Baie Trinité. Much of the sandy matrix has been removed. Map unit 2d.

Figure 3-8 Bouldery rapids in the bed of Petite Rivière de la Trinité, thought to be the remnant of an end moraine.

mentioned in Appendix E. Despite difficulties, penetration readings were fairly consistent both within sites and from one site to another. For all sites the average resistance is $4 \pm \frac{1}{2}$ kg/cm^2 (dense), but lenses of sorted sand were less resistant than average.

Water contents measured at various times over the summers ranged from one per cent to nine per cent of the dry weight; most readings were between three per cent and five per cent. Till soils drain rapidly, even after record rainfalls (e.g. September, 1972). Permeability tests were not performed either in situ or in the lab, but calculations from Beard and Weyl's tables (1973) yield porosities of 31-34% and permeabilities of about 10^{-2} to 10^{-4} cm/sec for sediments having the size and sorting characteristics of the till. Atterberg tests were performed on the -63μ fraction of four samples which had relatively high amounts of fines. Liquid limits varied from 0 to 14%. The till is non-plastic, as expected from material in which the fine fraction consists of silty rock flour.

Fabrics

Three-dimensional fabric analyses were undertaken to obtain data on ice flow directions, and to gain insight into conditions of glacial transport and deposition. However, only thirteen fabrics were completed because data acquisition was too time consuming in view of the inconclusive nature of the results; those fabrics are summarized below, and two-dimensional rose diagrams of them appear later as Figure 6-2, p. 155.

The interpretation of glacial transport and deposition mechanisms was based on the following assumptions:

1. In basal transport, elongated pebbles tend to travel parallel to the direction of glacial flow (south to southeast in the field area), and they

dip in an upglacier direction (Holmes, 1941; Harrison, 1957).

2. Englacially transported material tends to roll up shear planes and is therefore oriented normal to the direction of flow (northeast). The pebbles emplaced by this mode of transport would dip slightly in either a northeasterly or a northwesterly direction in the field. This orientation is always accompanied by its complementary (normal) principal mode (Glen, Donner and West, 1957).

3. In ablation till there is no overall orientation or dip direction.

On the basis of these assumptions, the fabrics from Lac Nadeau and minor moraines can be interpreted as basal till. The Mile 12 sample has a northeasterly orientation, but the dip of the pebbles and a secondary mode are oriented in a northwesterly direction. This fabric is interpreted as having both a basal (NW) and an englacial component. The Walker Lake fabric is similar and in both cases the englacial component would seem to dominate. The Crooked Lake, Lac à Tabac and Daigle samples have some orientations in the supposed direction of flow, but no preferred dip. The sample from the left bank of Petite Rivière de la Trinité is multimodal. Two peaks lie in the northwest quadrant but the dip is strongly south. The fabric may be the result of later reworking and imbrication by waves coming in from the open Gulf. The small loop moraine near Godbout is interpreted as basal till from a valley glacier, since the fabric is oriented in the direction of the local valley structure. The reason for the strong east-west orientation in the Lac Dupont fabric is not apparent, because lithological data suggest that the till is basal and derived from the north-northwest.

Inspection of the fabric diagrams will show that these fabrics do not fall clearly into any of the transport mode categories above. Most of the diagrams have broad modes or are multimodal. Furthermore, Chi-square contingency tests (Middleton, 1965) show that with the exception of the minor moraines, Lac Dupont and Lac Daigle samples, the modes do not represent statistically significant preferences. On this basis alone, the material would seem to be ablation till.

Besides the insufficient number of samples and the multimodal characteristic of the fabrics, the fabric results are inconclusive for several other reasons:

1. The late glacial history of events is not clearly understood. Some fabrics could be the result of local lobing or splaying of the ice front.
2. During the extraction of pebbles it was noted that these clasts were oriented along streamlined paths around boulders and even cobbles. With this in mind, it is concluded that the fabrics probably do represent stress directions within an active glacier, but that in these coarse-textured tills they are a response to very local rather than regional forces.
3. An ablation till origin is inconsistent with some of the mineralogical data, which is indicative of transport distances so small that the material must have travelled in the sole of the glacier.

Composition

(a) Clasts

pebble lithologies

At twenty-two sampling sites,sets of one hundred pebbles, one to three centimetres long axis, were collected. At these locations, hand specimens from the adjacent bedrock were also obtained to aid in the identification of lithologies and in the interpretation of results. The lithology of pebbles which tended to disintegrate were determined in the field; the remainder were cracked in the laboratory and identified with the aid of a hand lens. Table 3-2 shows the proportion of various

Table 3-2 **Pebble lithology** (in per cent)

	L du Portage	Là la Ligne	Loop moraine	Godbout	Là Tabac	L Blanc	Crooked L	L Nadeau	Minor moraine	B Trinité	P Riv Trinité	Pentecôte W	Dupont	Riverin	R Vachon	L Walker	L Hall	L des Rapides	Cross moraine	Daigle U	Daigle L	Mile 12
Sample # (west end → east end)	87	91	96	84	80	78	77	75	71	63	61	39	41	30	31A	55	51	25	31	16	14	10
granite/gneissic affinity																						
pink granite	12		11	10	14	5	11	7	18	22	14	30	5	9		6	16	10	11	25	22	$\boxed{25}$
grey granite		20	13	10	7	4	6	11	5	9	10	6	7	4		9			4	3	2	35
pink granite gneiss	24	12	14	4	20	33	25	25	29	21	$\boxed{21}$	$\boxed{12}$	13	15		$\boxed{32}$	13	16	23	4	22	8
grey granite gneiss	$\boxed{16}$	$\boxed{32}$	$\boxed{16}$	$\boxed{26}$	18	$\boxed{18}$	$\boxed{9}$	$\boxed{3}$	$\boxed{17}$	$\boxed{17}$	$\boxed{19}$	$\boxed{6}$	7	18			7	11	16	9	11	18
biotite gneiss	16		6		$\boxed{5}$	4	$\boxed{11}$	21	4		8	2	10			4		2		5	6	
biotite schist		4	2		5	5	4	10	5	9		4	6	4		11				3	8	5
hornblende schist		4		8										6						4		
mafic affinity																						
diorite																				4		
monzonite	8	4	6	4		2						10		12			6					
gabbro	16		13	12	10	2		7	4		5	10	32	4	14		$\boxed{14}$	$\boxed{31}$	$\boxed{30}$	14	13	3
anorthosite	4				2		2					4	$\boxed{4}$	$\boxed{4}$	$\boxed{79}$	4				2	2	
diabase				4			3					2		2		2			8	3		
green granulite		8		8		11	11	8	3	4	2			6		4	18	21		12		2
red granulite	4		6	8	8	5	6	3	2	5	17	2	6	6		16	12	2		$\boxed{3}$	$\boxed{14}$	1
syenite													2									1
quartzite				4		6	1		2	1	2			1			4	1				
mineral fragments		12	4		3	3	3		6	4	2	6	2	6		4	3	4	8			2
disintegrated rock		4	9	2	8	2	8	2	5	8		6	6	3	7	6	7	2		9		
unknown								3														
sulphides/pyrite		t																		t		

Relative Roundness

	87	91	96	84	80	78	77	75	71	63	61	39	41	30	31A	55	51	25	31	16	14	10
round	48	28	33	34	25	15	38	30	40	34	23	24	16	28		46	34	48		57	47	25
																			68			
sub-round	24	36	45	40	37	56	40		50	44	70	40	48	36		35	34	31			33	45
								47												39		
sub-angular	20	32	17	22	22	27	19		10	22	7	26	24	34		17	30	19	32		17	30
angular	8	4	5	4	16	2	3	23				10	12	2	100	2	2	2		4	3	

□ square indicates underlying bedrock lithology as determined in the field and from bedrock geology maps

t trace

Sites are located on Figure 2-2

lithologies at each site given in per cent, together with the underlying or adjacent bedrock lithology. The pebbles collected generally had no surface markings, such as striae or percussion marks. Most had equant to prolate shapes, but faceted surfaces were not uncommon.

Granites and granite gneisses are the major component of the pebble fraction. These rocks were subdivided into pink and grey varieties according to the relative abundance of potassic feldspar. With the exception of site 74-31A, which consists of crushed anorthosite, these lithologies account for 36% to 91% of the clasts, and those tills which overlie granitic rock have percentages exceeding 58%. The pebbles in this category are usually rounded to subrounded and fresh in appearance.

Gabbros, monzonites and anorthosites are less abundant. The gabbros are pyroxene-rich but they also contain olivine; pebbles classed as anorthosite were generally plagioclase cleavage fragments. These pebbles on the whole were subangular but some of the angular clasts were also in this category.

Granulites, which ranged from round to subangular in shape, were divided into a green variety, rich in quartz and pyroxene, and a red variety, which has quartz and feldspar as major components. A number of these pebbles had alteration rims or tended to disaggregate into sand-sized grains when struck with a hammer. Pebbles of this type in the present soil zone were particularly weathered.

Biotite and hornblende schists are also present in the pebble fractions of the till. The pebbles formed from these rocks shear along schistosity planes, and with the gabbroic types, make up almost all of the angular clasts.

Syenite, diabase, diorite and monomineralic fragments are minor clast components. The majority of the unidentifiable and completely weathered rocks were mica-rich, but a few consisted of an extremely fine powder. No carbonate rocks were identified, although both marble and limestone have been reported as occurring within the field area.

Interpretation of the petrographic data

The abundance of a particular pebble lithology depends on several factors:

1. The lithology of the rock over which the glacier passed, and the direction of the ice flow.
2. The position of transport of the material within a glacier, which determines the relative abundance of distant and local rock fragments. It is assumed here that at least the local material is basally transported.
3. The structural and textural characteristics of the bedrock, which determine the ease of quarrying and crushing, and the size of the crushed material. In the field area, most of the bedrock is coarse-grained and therefore ultimately produces sand-sized particles. The mafic rocks also have joints which create boulder-sized material.

The dominance of the granites and gneisses can be attributed to occurrences of these rock types in an up-glacier direction, and at many sites, directly below the till as well. Minor changes in composition are assumed to be caused by small lithological differences in the bedrock to the north.

The incidence of quantities of gabbro-anorthosite-monzonite in excess of 30% corresponds to areas where the bedrock adjacent to the samples is mafic. When gabbro percentages are high, relatively high amounts of granulites are present as well. These are probably derived from zones of high grade metamorphism near the peripheries of the mafic intrusives, although such zones have not been identified on bedrock maps. The pronounced increase in mafic pebbles in tills overlying the gabbroic rocks suggests that the tills have a large local component and therefore consist primarily of material transported near the base of the glacier. On this basis the ground moraine would be classed as basal till rather than englacial or supraglacial ablation till (which the fabrics, taken alone, suggest). This conclusion is supported by the subangular morphology of the clasts, which may indicate that there has been insufficient time for comminution.

Data from several sites show inconsistent pebble lithology compared to the local bedrock. (1) Sample 74-39 (Pentecôte west), for instance has high amounts of both gabbro-monzonite and granite gneisses, although the underlying and adjacent rock is granitic. The mafic component has therefore been attributed to nearby gabbros which are north and west of the site. (2) The Riverin Valley till (part of the Valley Front moraines; sample 74-30) has a mafic component of less than 30%, although it is underlain by anorthosite. This suggests that the till deposited in this moraine was not all basally transported, that a large component had an englacial origin and was possibly deposited after travelling up shear planes near the glacier snout. The material would thus be derived primarily from the gneissic rocks about 10 km upvalley. (3) The Daigle moraine samples (74-14 and 74-16) are also anomalous since the moraine has greater quantities of granulite and gabbro than would be expected in primarily granitic rocks as mapped by Faessler (1942). The nearest mafic body lies to the north-northwest. It is therefore suggested that the gabbroic clasts originated from this body and that the glacier was flowing from a north-northwesterly direction.[1]

(b) Matrix (1): Analysis of the sand fraction at two sites

A detailed mineralogical examination of the sand range was undertaken for two samples which represent the two main types of till: the Mile 12 till, which is primarily granitic and overlies granitic bedrock, and the Dupont till, which rests on a gabbroic anorthosite body. Analysis of these two establishes the composition of the matrix for tills of this area and indicates the variation that can be expected from the two main bedrock types. For this study the investigation considered the sand range between 0.063 mm and 1.0 mm; coarser material consists of rock fragments.

Samples were dry sieved, placed in an ultrasonic bath to remove coatings of iron oxide, and later rewashed through sieves. Heavy and light minerals were then separated using tetrabromoethene (SG = 2.95). This procedure was followed for all fractions less than 1.41 mm, the diameter of the stop-cock openings, but because rock fragments are common in the +0.7 mm fraction, the coarse sand heavy liquid separation is inaccurate. Materials less than 0.25 mm were examined with a petrographic microscope using transmitted light. Those greater than 0.25 mm were studied under a binocular reflecting microscope.

Light/heavy mineral ratios

Figure 3-9 shows the relationships between heavy mineral ratios,

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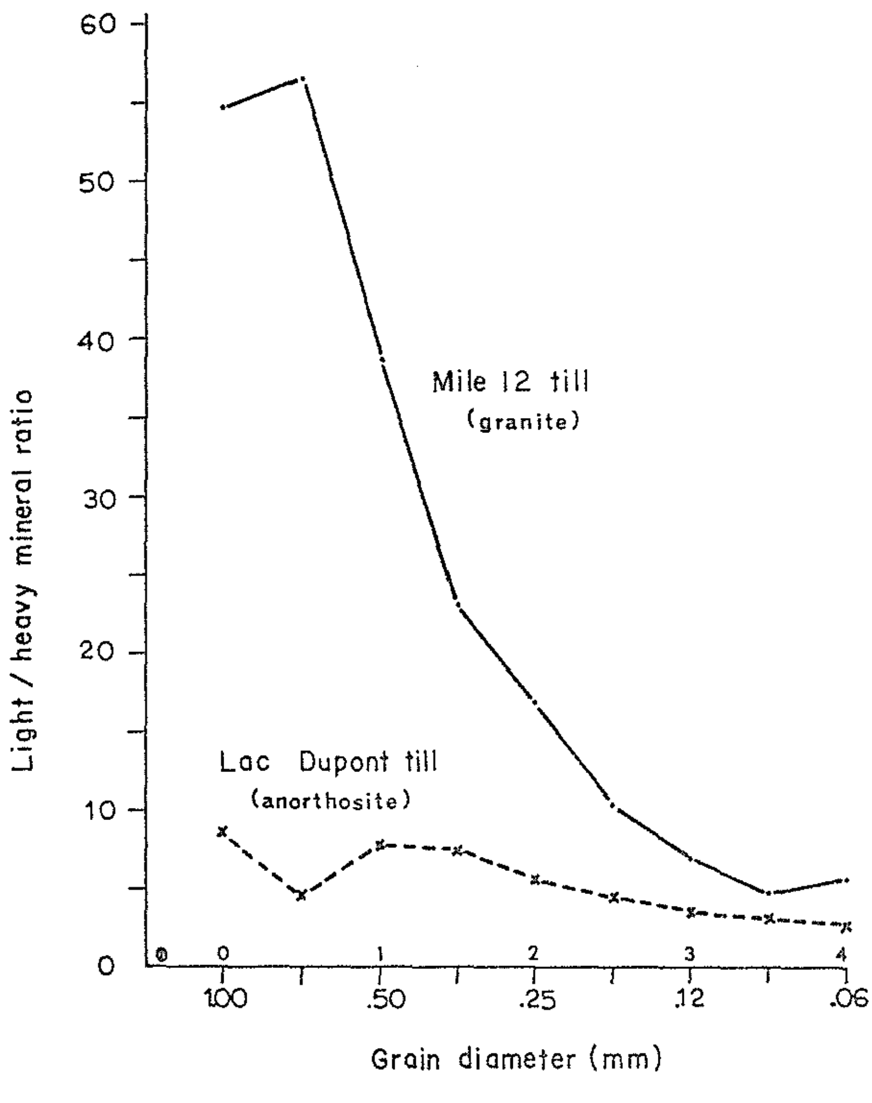
[1] It should also be noted that the upper and lower Daigle samples were lithologically similar even though textural characteristics described previously would tend to indicate that the upper material was ablation till. The lithological evidence suggests that the difference in state is related to postglacial soil development and/or subaerial erosion and that both samples represent the lower basal component of basal melt-out till.

Figure 3-9 Light / heavy mineral ratios, North Shore till



grain size, and rock source.

1. The light/heavy ratio for the granitic till ranges from 56 to 5.0, while for gabbroic till the range is only from 8.5 to 2.5: heavy minerals are more abundant in the gabbroic till over the entire grain size distribution. This difference is due to the basic mineralogical composition of the source rock.

2. At both sites, the relative amount of heavy minerals increases as grain size decreases. This is attributed to the fundamental characteristic that heavy accessory minerals are usually small in size.

3. For any given ratio (e.g. 5.0) the gabbroic tills are coarser. This trend may be related to the proximity of the gabbros to their source (the granitic rocks being more comminuted) or to inherent crushing characteristics. In addition, deep seated basic magmas are less viscous than non-basic magmas and therefore tend to grow larger crystals.

Mineralogy, by grain size

The following minerals have been reported from bedrock in the Quebec North Shore area within or adjacent to the study area (Faessler, 1942a):

light-essential:	plagioclase, biotite, quartz, orthoclase, microcline, chlorite, muscovite
accessory:	scapolite
trace:	calcite
heavy-essential:	hornblende, hypersthene, augite, olivine, diopside
accessory:	apatite, garnet, magnetite, ilmenite, sphene, pyrite
trace:	zircon, epidote, leucoxene, clinozoisite, wollastonite, zoisite, tremolite, kyanite, sillimanite, anthophyllite.

The principal mineral components of the two tills, by grain size, are summarized by Table 3-3. Block diagrams of those minerals constituting more than 10% of any fraction have also been constructed (Figure 3-10) so that trends can be more readily appreciated.

For the light minerals quartz is dominant, composing between 37% and 86% of the total fraction. Although the relative abundance of quartz in Figure 3-10 is similar in both tills, the actual quantity is much higher in the Mile 12 sample because light minerals are more abundant. The quartz is commonly strained, as indicated by an undulating extinction, and grains are angular and irregular in shape. Feldspars are also major constituents, and plagioclase is particularly important in the Lac Dupont till, where it appears as lath-like cleavage fragments. Because most grains have a refractive index greater than balsam, the composition is presumed to be more calcic than oligoclase. Most of the feldspar appears to be unweathered, although the outer edges of a few grains showed twinned laths with excessively low birefringence; these anomalous patterns were suspected to be altered plagioclase.

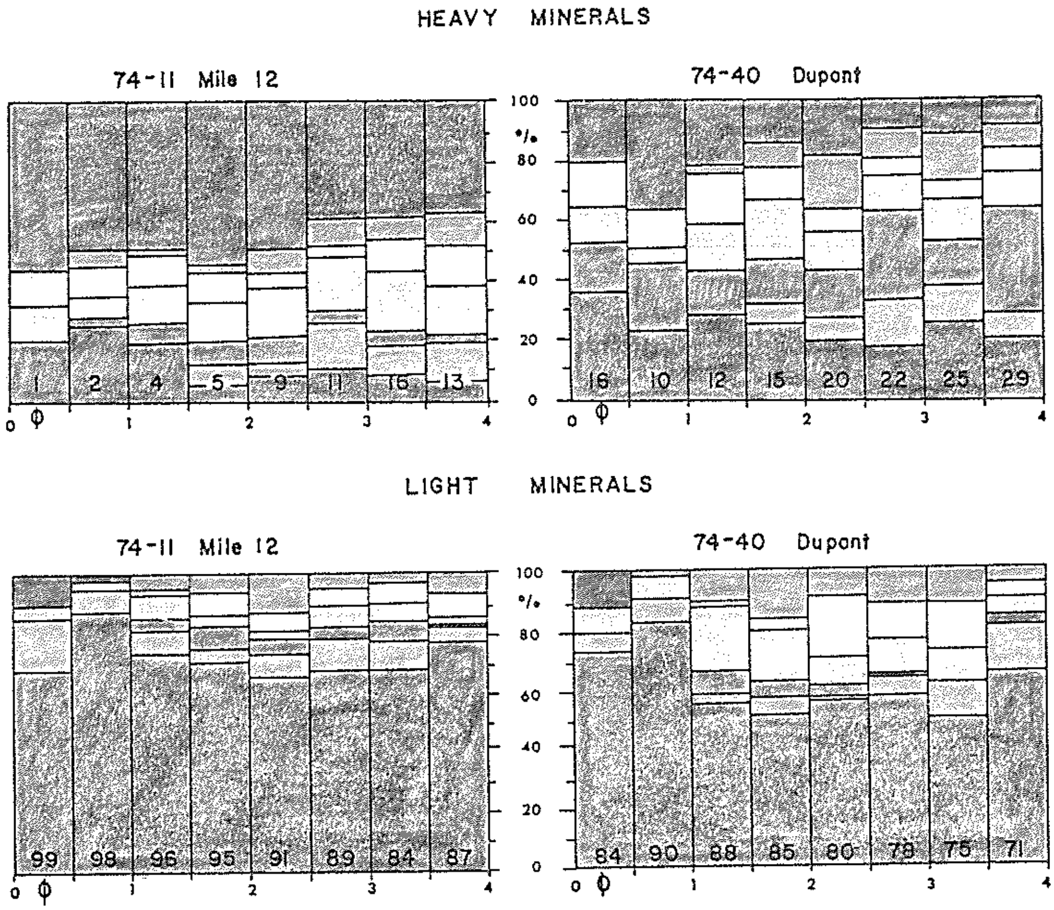
In the heavy fraction, amphibole and pyroxene are of major importance. Hornblende is the predominant heavy mineral ranging in value from 37% to 56% of the heavy fraction at Mile 12 and from 9% to 37% at Lac Dupont (range is 2-6% of the total sand fraction). In both samples the relative importance of these minerals appears to decline as grain size decreases (cf Figure 3-10), although actual counts increase because the light/heavy ratio is lower in this part of the sand size range. The hornblende appears as unaltered, nearly opaque, dark grains with rounded edges, although cleavage surfaces are visible. Heinrich (1965) claims that the dark colour signifies an abundance of ferrous (2++) ion. The pyroxenes are also important, especially in the Dupont sample, where the clinopyroxenes range from 16% to 35% of the heavy fraction and orthopyroxenes

	□ •	□ •	□ •	□ •	□ •	□ •	□ •	□ •	□ •
grain size (mm)	1.00	0.71	0.50	0.35	0.25	0.17	0.12	0.08	0.06
Light Minerals									
altered plagioclase	0 0	0 0	0 0	2 2	3 8	16 6	9 5	12 6	4 7
plagioclase	5 5	8 4	7 3	19 8	16 4	8 3	9 6	8 5	4 2
chlorite	0 0	0 0	0 0	0 0	4 0	0 1	2 0	3 0	1 1
biotite	0 0	0 0	1 0	4 0	3 3	3 2	4 2	4 2	1 3
quartz	67 45	61 67	75 86	49 70	43 66	46 60	44 60	37 57	47 66
sericite/chlorite	0 0	0 0	0 0	4 1	5 3	3 6	3 1	2 0	1 2
muscovite	0 0	0 0	0 0	0 3	1 0	1 2	0 0	0 0	0 0
orthoclase	2 17	5 18	7 8	3 8	5 4	1 7	6 10	9 8	11 5
microcline	0 0	0 0	0 0	7 4	5 7	3 5	1 4	0 6	2 1
rock fragments	16 32	10 10	0 1	0 0	0 0	0 0	0 0	0 0	0 0
Heavy Minerals									
augite	3 0	6 0	2 1	3 1	4 0	4 1	4 1	6 1	5 1
hypersthene	0 0	0 0	0 0	0 0	1 0	2 0	4 2	3 2	2 2
garnet-pink	2 0	3 0	2 0	1 0	2 0	2 1	5 0	2 0	6 0
garnet-colourless	0 0	0 0	0 0	1 0	0 0	1 0	2 0	2 1	5 0
apatite	1 0	2 0	1 0	2 0	2 1	2 1	1 1	1 2	2 2
magnetite	1 0	2 0	1 0	2 1	3 1	2 2	3 2	3 3	3 2
hornblende	3 1	3 1	4 1	3 2	2 3	4 4	2 5	3 6	3 5
sphene	0 0	0 0	0 0	0 0	1 0	1 0	0 0	1 1	0 1
olivine	0 0	0 0	0 0	0 0	0 0	1 0	1 0	2 0	1 0
tourmaline	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 0	1 0
diopside	0 0	0 0	0 0	0 0	0 0	1 0	0 0	0 0	1 0
actinolite	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 0	0 0

Table 3-3 Principal mineralogical components of two contrasting till samples:

- □ 74-40 Dupont till, overlying anorthosite
- • 74-11 Mile 12 till, overlying granite gneiss

Values given are expressed as percentage of total grains counted at each site and for each size fraction.



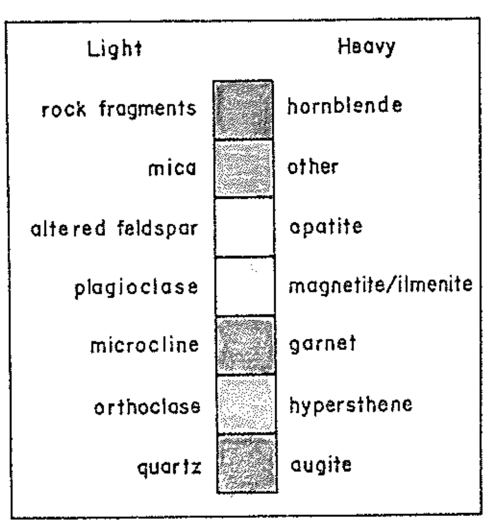


Figure 3-10

Mineralogy of the matrix,

North Shore till

Numbers within blocks denote relative percentages of heavy and light minerals in each size fraction account for 7% to 16%. The grains appear as unaltered (no alteration rims), slightly rounded, cleavage fragments. They are more angular in the Dupont sample than at Mile 12. The clinopyroxene is pale green and is interpreted as being augite with a high Fe++ content (Heinrich, 1965). The orthopyroxene shows pronounced red-green pleochroism and it has been interpreted as hypersthene. Angular garnet fragments are also abundant in the Dupont sample and account for 15% to 36% of the heavies. Garnet is much less abundant in Mile 12 till. Apatite and opaque minerals (magnetite-ilmenite) are also present and together make up as much as 33% of the heavy fraction.

The gross mineralogical breakdown can be related to the nature of the bedrock over which the glacier has passed. Acid intrusive rocks are high in quartz, hornblende and potassic feldspar, and these mineralogies are prevalent in both samples because the majority of rocks in an upglacier direction are acid gneisses. Mafic and ultramafic rocks have abundant plagioclase and pyroxene, which accounts for the relatively higher quantities of these mineralogies in the Dupont sample, where glaciers have over-ridden the underlying and nearby body of gabbroic anorthosite. The abundance of garnet in the Dupont sample is unexpected, but garnets may be derived from high grade metamorphic bodies which may lie between the low grade gneisses and the intruded ultramafic cores, although such sources are not indicated on the existing generalized bedrock geology maps of the area. Apatite and magnetite are accessories in both rock types. Hornblende is an accessory in gabbro, and pyroxene is an accessory in gneisses, further adding to the mineral diversity.

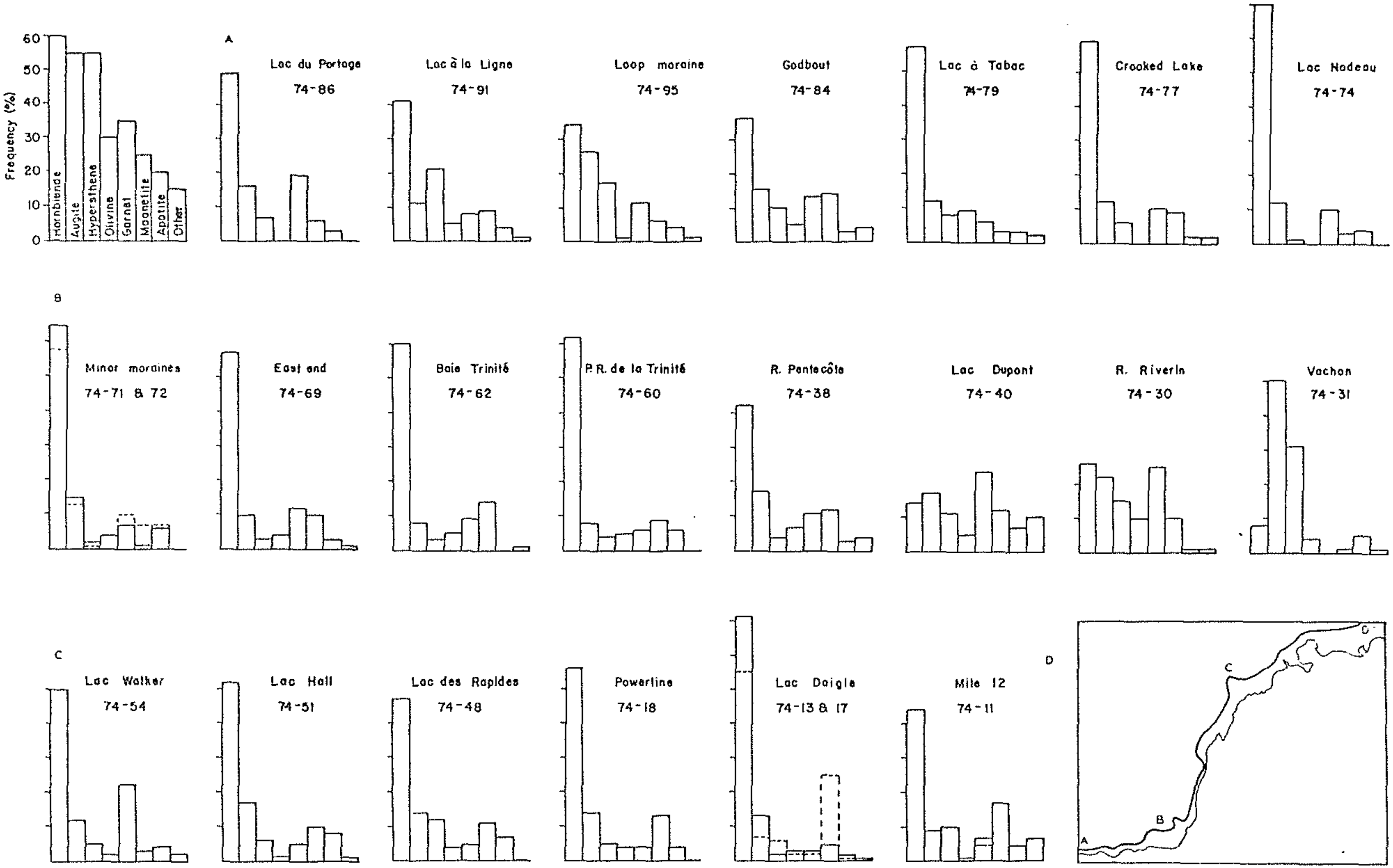
(b) Matrix (2): Heavy minerals in the fine sand fraction (0.125 - 0.250 mm)

Analyses of the Mile 12 and Dupont samples show the distribution of minerals in the various size-fractions. This section attempts to show how the minerals in one of these fractions is distributed spatially along a traverse in the field area. The range 0.125 to 0.250 mm was selected for heavy mineral analyses, for several reasons:

1. Petrographic identification is easier in the medium and fine sands.
2. This fraction is representative of a substantial portion of the till matrix. Vagners (1969) and Gwyn (1971) concluded that the mean size of heavy minerals in tills of Southern Ontario is 3.62Ø but since North Shore tills are not far travelled and derive from different rock types the mean size is slightly coarser (< 3Ø).
3. Figure 3-9 shows that the light-heavy ratios from different source rocks are distinct in this range, so a mineralogical analysis of this fraction can be used to determine provenance.
4. The fine and medium sands are commonly examined by other workers (e.g. Sitler (1963) 0.125 - 0.144 mm; Connally (1964) 0.062 - 0.35 mm; Dreimanis _et al._ (1957) 0.15 - 0.83 mm; Harrison (1960) 0.125 - 0.50 mm; Gwyn (1971) 0.125 - 0.250 mm). Results can therefore be used in comparative studies.

Figure 3-11 shows the heavy mineral assemblages for sites across the field area. From this graph it is apparent that hornblende is the predominant heavy mineral, with percentages ranging from 8% to 71%. The pyroxenes, augite and hypersthene, are also major components of the heavy fraction. The augite content ranges between 8% and 50% and hypersthene varies from 3% to 21%. Olivine and garnet, and to a lesser extent, magnetite and apatite, also contribute to the mineral suite.

Figure 3-11 Heavy mineral traverse, Lac du Portage to Moisie River



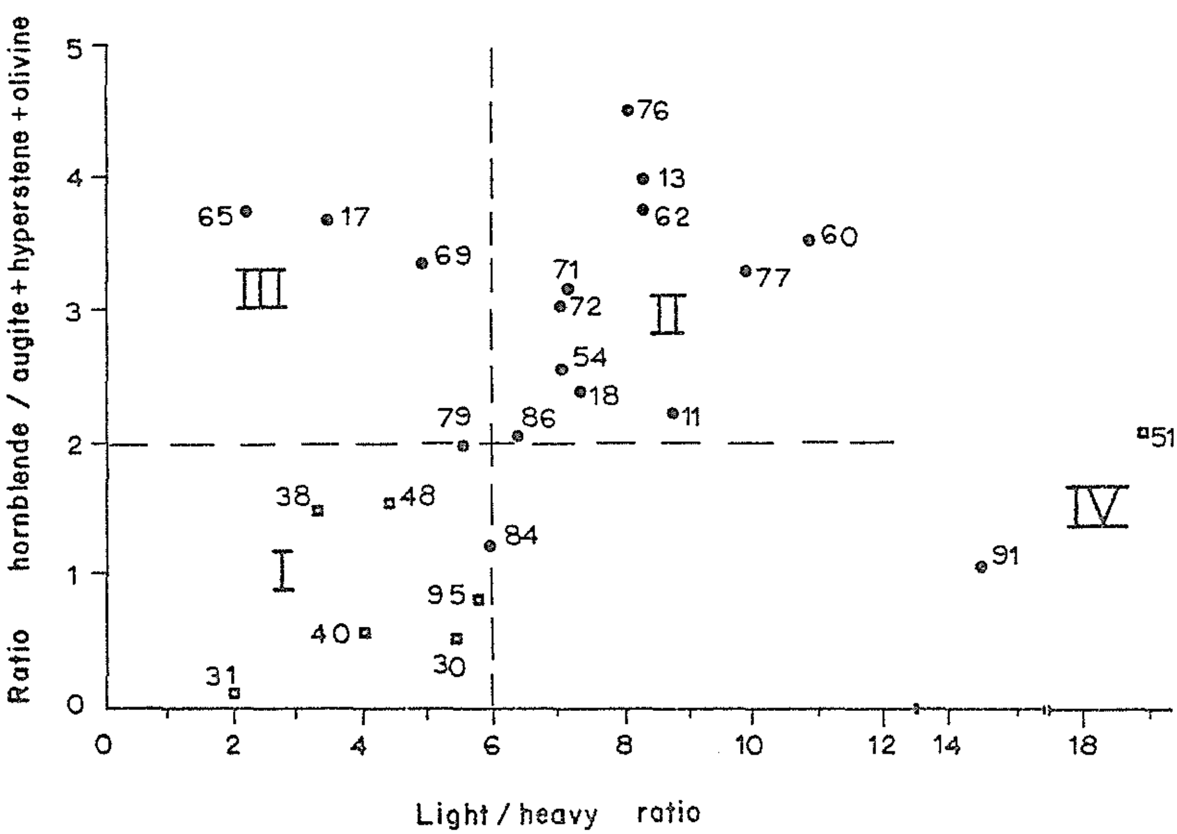
The graphs also show that there is no systematic overall variation over the field. Therefore, in order to account for the results a second graph, relating abundance of heavy minerals and types of minerals, was contructed (Figure 3-12). From this, samples were clustered and then compared to the bedrock and pebble lithologies. Interpretations were based on the assumptions that:

1. the light/heavy mineral ratio of a sample is a function of the general rock type from which the till is derived. This has been empirically shown to be the case in the Mile 12 and Dupont till samples. The light/heavy ratio exceeded 8.8 where the till was underlain by granitic rocks, and fell to 4.0 where nearby and underlying rocks were gabbroic.

2. certain mineral varieties are associated with granitic and mafic bedrock types. Although considerable overlap occurs, hornblende is generally characteristic of granites and gneisses, while augite-hypersthene-olivine is common to gabbros, anorthosites and monzonites. This relationship is derived from the bedrock reports (Faessler, 1942a; 1945) and is supported by the results of the Mile 12 and Lac Dupont data.

Figure 3-12 shows that most of the till samples plot into two mutually exclusive domains on the basis of these parameters. The first domain consists of samples which have an abundance of heavy minerals and a high pyroxene-olivine level. On bedrock maps these sites are all underlain by anorthositic gabbros. The Vachon site (74-31) actually consists of crushed and slightly disturbed bedrock which was probably pushed by, but never incorporated into the ice, and therefore is not a true till. Hornblende accounts for eight per cent of the heavies in this sample and the hornblende/pyroxene ratio is 0.1. These values are assumed to

Figure 3-12 Relationship between heavy mineral ratios and the mineralogy of the heavy fraction



till samples underlain by granitic rock (•) and mafic rock (▫)

represent the amount of hornblende expected in the gabbroic bedrock itself. Higher values in all other samples were presumably derived from granitic rocks to the north of the mafic bodies. The pyroxene grains in this sample were all extremely angular, but in all other cases they were subangular to subround. The Dupont sample (74-40) is the gabbroic standard, and has been discussed previously. The light/heavy ratio is 4.00 and the hornblende/pyroxene ratio is 0.55. The Riverin sample (74-30) lies atop the same anorthositic intrusion as the Dupont sample. It has similar pyroxene levels, but contains more light minerals. The pebble fraction also had some lithologies associated with acid-phase rocks, and in both cases this situation may be attributed to the deposition of englacial material derived from beyond the ultramafic body. The Pentecôte sample (74-38) has a slightly high hornblende level, corresponding to an abundance of granitic rocks in the pebble fraction, but as discussed previously, rock chips taken at the site indicate that some of the bedrock in this vicinity is granitic. The same is true in the Loop moraine area (74-95). The sample has a high pyroxene-olivine level in accordance with a gabbroic affinity, (the underlying rock type indicated on the bedrock map) but like the Pentecôte sample, it contains many light minerals, most of which are quartz and potassic feldspar. Rock chips taken from near the till site were a grey granite gneiss; obviously then at least portions of this area are granitic.

Sites in the second domain in Figure 3-12 all have a relative abundance of light minerals and high hornblende levels. They are underlain by granites and gneissic rocks and have these rock types surrounding them. The Lac à Tabac (74-79) and Godbout (74-84) samples, which fall at the margins of the domain, contain more heavy minerals, especially pyroxene, than the other samples. This condition has been attributed to the incorporation of mafic materials from gabbros lying to the west and northwest of the site. The Godbout sample has more mafic affinities because the gabbros are more extensive to the north and west of the Godbout area than at Lac à Tabac, and the sample is closer to the contact than the Lac à Tabac sample.

Samples in the third domain are underlain by granitic rocks and have hornblende ratios similar to their counterparts in domain II but low light/heavy ratios. The minor moraines sample (74-69) was extracted from the wave washed eastern portion of the minor moraines west of Baie Trinité, and the Dump site (74-65) is the reworked equivalent of the Baie Trinité till (74-62). Their position on the graph suggests that the low light/heavy ratio is a function or winnowing, with the subsequent transport of light particles and concentration of heavies.

The Lac à la Ligne (74-91) and Lac Hall (74-51) sites fall beyond the main clusters. The Lac à la Ligne area is underlain by augen gneiss. The till has an abundance of light minerals but is low in hornblende. One possible interpretation would be that pyroxene and olivine were incorporated as the glacier travelled over a gabbro body about five kilometres northeast, but this hypothesis is not supported by pebble data, which shows a predominance of granites and gneisses, or by other ice flow directional data. The Lac Hall till has excessive amounts of light minerals and a high hornblende content for till which is supposed to overly gabbro. There are two possibilities which explain this. Firstly, the bedrock could be a pyroxene-granulite rather than gabbro as mapped. Secondly, the area lies south of a scarp face 200 m high. Material deposited on the lower lee slope may have been englacially transported from granitic sources to the north.

(b) Matrix (3): Comparison of heavy mineral results with studies in other areas

Table 3-4 presents heavy mineral summaries of Grenville-derived tills in eastern Ontario from sites near the Shield, and the results of this study. These results are not strictly comparable since the various authors used slightly different size ranges and different expressions of central tendency (e.g. Dreimanis used modal scores instead of means).

Total heavy mineral percentages obtained from North Shore tills are similar to those of Dell (1963); however, they resemble the Superior-Southern provenance tills of Dreimanis et al. (1957) and Gwyn (1971) more closely than those derived from Grenville sources. The divergence from the results of Dreimanis et al. may be due to the different grain sizes used.

The suites of minerals are similar in both regions, although actual percentages vary. Hornblende is the dominant mineral in all cases. The major differences appear in orthopyroxene and tremolite/actinolite percentages. Orthopyroxene is a major constituent of basic and ultramafic bodies. The higher orthopyroxene percentage in North Shore tills is probably a reflection of the greater extent of these rock types in the Grenville province along the North Shore. Similarly, the low percentage of tremolite/actinolite may be related to the scarcity of crystalline limestones in the area investigated, since high tremolite/actinolite percentages in eastern Ontario Grenville rocks are associated with metamorphosed carbonates.

In the past, total garnet percentages and garnet colour ratios have been used to differentiate source areas (Dreimanis et al. 1957;

Table 3-4 Comparison of Heavy Mineral Assemblages and Garnet Ratios in Grenville Sands

	North Shore: this study (f. sand)			Gwyn, 1971 Ontario	Dreimanis *et al.*, 1957 Ontario		Dell, 1963 E. Grenville area, Ontario
	mean	granitic source	mafic source	(f. sand)	(f.-c. sand)		(v.f.-f. sand)
% heavies	14	13	19	34	3-8 [¤]	(6)*	13
Assemblage							
hornblende	48	55	31	46	18-55	(49)	73
clinopyroxene	15	12	22	19	0-6	(<1)	9
orthopyroxene	8	6	15	1	0-13	(2)	1
olivine	4	3	5	-	---		-
garnet	10	9	11	14 {West 20, East 10}	7-48	(4,7,27)	12
magnetite/opaque	9	9	9	14	3-24	(8)	10
apatite	4	4	4	-	---		+
tremolite		+		6	2-35	(12)	+
epidote	1	+	1	1	0-6	(1)	+
zoisite				1	0-5	(1+4)	
sphene	1	1	1	1			+
chlorite-serpentine					1-16	(2)	
Garnet ratio:							
purple + colourless / red	0.9	0.8 (0.6-0.5) (mode)	0.9 (0.9)	0.8 W < 1; E > 1	0.2-28	(0.3)	0.5
Superior province ratio				3	.2-8	(1.2)	4.3

¤ Range of percentages in samples and * most frequent percentage(s)

Connally, 1964; Gwyn, 1971). The total garnet percentage from 24 North Shore till sites is similar to the eastern Grenville results of Gwyn (1971) and Dell (1963). The overall ratio of purple and colourless garnets to red is comparable to the result of Gwyn's work and only slightly exceeds values obtained by Dreimanis and Dell. However, for this study, gradational pinkish garnets were lumped in with the red varieties; if these had been included in with the purple count, the garnet ratio would have been similar to Dell's and Gwyn's values from Superior, not Grenville, province. From this, it would seem that either garnets are not accurate indicators of provenance or that colour classifications are imprecise when a large proportion of the garnets have intermediate tinges.

(c) Mineralogy of the silt-clay fraction

The silt-clay fraction accounts for less than 10% of the till matrix, (and most is medium to coarse silt). Because it comprises only a small percentage of the till and its character does not affect the engineering behaviour of the till, only two samples of Mile 12 (74-11) and Dupont (74-40) were analysed, by X-ray diffraction techniques using CuKα radiation.

Powder diffractions of air dry, heated, and glycolated samples of the -63u fraction, summarized by Table 3-5, show that the principal minerals are quartz and feldspar, although pyroxene is also important in the Dupont sample. Micas, garnet and amphibole are of less importance. As expected by the predominance of coarse silt, most of the powder is rock flour, and there are few clay minerals. Since the fine fraction of a till commonly represents contributions from remote sources (while coarser fractions have more local origins), the mineralogy of the fine fraction of these two tills is less distinctive than the corresponding assemblages in

Table 3-5 Silt-clay Mineralogy of the Mile 12 and Dupont till samples

		Principal minerals	Other minerals, in order of decreasing importance	Remarks
Mile 12	powder	quartz, feldspar	amphibole, mica, magnetite, trace calcite	few clay minerals
	-5μ	mica-illite	quartz, feldspar, mica, pyroxene	sharp decline of quartz, feldspar
	-2μ	mica-illite, feldspar	mica-illite, poss. kaolinite and montmorillonite	
Dupont	powder	plag. feldspar, quartz, pyroxene	biotite, amphibole, chlorite, garnet	
	-5μ	mica-illite, chlorite, pyroxene	feldspar, ilmenite, biotite, trace vermiculite	high background; Amorphous material significant
	-2μ	? chlorite/halloysite	minor fieldspar	no peaks. Colouration at 575^{o} suggests chlorite

the coarser fraction. For instance, the Mile 12 (granitic) sample has peaks of plagioclase and pyroxene, while the Dupont (ultramafic) sample shows the presence of amphibole.

As grain size diminishes, there is a decline in the relative abundance of feldspar and quartz, and a corresponding increase in mica or mica-illite, and also chlorite in the Dupont sample. This trend agrees with other work which shows that the -2μ fraction of Labrador till consists mostly of illite and chlorite (Piper, 1975). Both samples, but especially the Dupont, probably contain some non-crystalline materials, since the peaks of even the major minerals are poorly defined. McKyes, Sethi and Yong (1974) have attributed similar occurrences in their diffractions of the St. Vallier and St. Louis clays in southern Quebec to the presence of amorphous iron and silica oxide coatings on the mineral particles. Since non-crystalline materials are more abundant in the Dupont till it is suggested that the material could be related to weathering products of ultrabasic rocks.

Additional tests for fine-grained carbonates were performed using Chittick apparatus and the method outlined by Dreimanis (1962). The calcite content of the -63μ fraction of each sample was less than 0.5%, and dolomite was absent.

(d) Summary of lithological data

1. The light/heavy ratio obtained for a sample is a function of the grain size selected, and the general lithological characteristics of the parent rock.

2. For any given size range of heavy minerals, till associated with granitic rocks has high hornblende content, while that associated with gabbroic rocks has significant pyroxene and olivine contents. These

differences permit differentiation of a till on the basis of possible source rocks.

3. Petrological variations in the till correspond to major variations in underlying bedrock type or to the lithology of the bedrock immediately northwest.

4. The data show that both the pebble and sand components possess the characteristics of the underlying and surrounding rock type. This indicates that, for mafic rocks, at least, (which have very limited extents) crushing must have occurred readily. The rock therefore may have either been generally weak, weathered, or prepared by frost action, but the absence of fines tends to refute the last two possibilities.

5. The abundance of local material suggests a basal transport mechanism. The till is therefore not ablation material, despite its textural characteristics and sedimentary structure.

6. The dominance of hornblende in the sand grains and of the granitic pebble fraction in tills overlying gabbroic intrusions indicates that distant rock sources are also important contributors to till lithology.

3.3 Stratified Deposits Related to Ice Fronts

Ice contact deposits

Ice contact deposits are of extremely limited extent in the field area. Pitted kame terraces do occur as narrow strips of bouldery gravel in the major valleys where terraces are present above the marine limit, and a few eskers are present in the area. Aside from these, ice contact stratified drift is limited to three sites, which have different combinations of sedimentary structures and textures, and therefore each one is described and interpreted separately below.

1. Lac des Rapides

The first complex is located along the southeast rim of Lac des Rapides ($50^{\circ}18'$N; $66^{\circ}24'$W). It has virtually no topographic expression because marine coastal processes have reworked the upper metre into a boulder-strewn terrace (at elevation 124 m). The best section (Figure 3-13) is the sidewall of a borrow pit, which exposes: ("a") one metre of subhorizontal, stratified, well-sorted sand, interpreted as beach deposit, sharply truncating; ("b") one half to two metres of coarsely stratified sand and gravel, and cobbly gravel. Beds dip southeast at angles between 20° and 25°. These strata overlie and merge with till ("c"), (sample 74-48). A large gabbroic (local) boulder $4\frac{1}{2}$ m long lies adjacent to the exposure in the pit. The stratified gravels are closely associated with till, both in terms of their stratigraphic position and textural characteristics, and it is suggested that they were deposited against melting ice which once filled the Lac des Rapides basin.

A second exposure (Figure 3-14) in the Lac des Rapides area is situated along the airstrip which occupies the next lower terrace (el. 110 m) 750 metres southwest of the previous site. The upper two metres ("d") are coarse beach sands, which are underlain by a line of rounded cobbles and pebbles ("e"). The lower two to three metres in the central part of the exposure consist of crossbeds of sorted sand and pebbles alternating with grey, very soft, silty sand; the finer sands are highly contorted and contain a large, irregular diamictic (σ = 1.35) inclusion ("f") in the western extremity of the exposure (right side of the photo). The contorted sand and presence of the diamicton suggest proximity to an

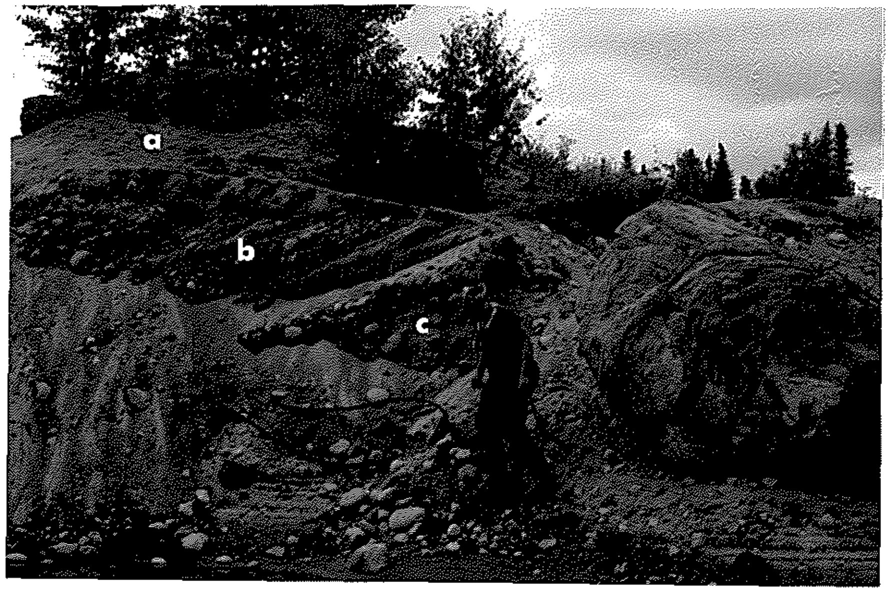


Figure 3-13 Pit exposure at 124 m ASL, Lac des Rapides

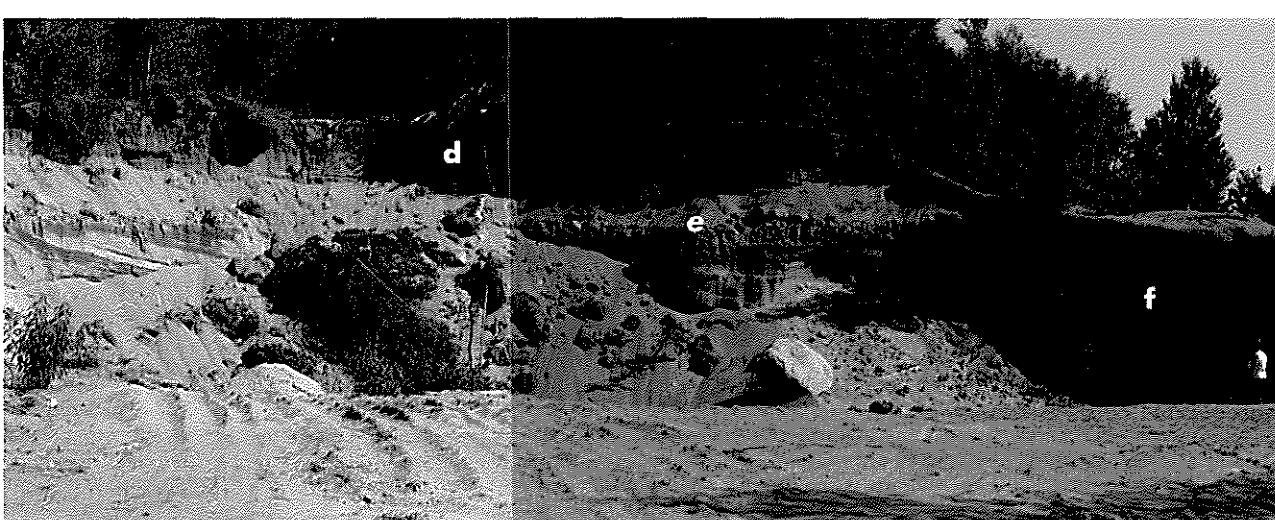


Figure 3-14 Pitwall exposure at 110 m ASL, Lac des Rapides.

ice mass. This, together with the cobbly layer which could be a lag remnant of interfingering outwash, or overriding till layer, suggest that these deposits were also associated with an ice mass occupying the Lac des Rapides basin. The fine silty sands suggest that the ice mass may have been partially submerged when these sediments were deposited. Since this site is well below marine limit, the Lac des Rapides ice block may therefore have been a remnant, disjunct ice mass.

2. Godbout

An ice contact complex is also exposed in pits five kilometres west of Godbout (49°19'N; 67°41'W). The surface elevation is about 105-115 m (the marine limit in the area). Poorly bedded to unstratified coarse gravels outcrop at the head of the pits ("g" on Figure 3-15) and extensively underlie the other deposits described below. These gravels appear to interfinger with and locally grade laterally into soft, moist, grey, fine sands in inconsistently dipping beds ("h"). One portion of these fine sands appears to be faulted, the fault block being reflected by a hollow on the surface ("i"). Farther along the eastern pit face a gravel lens is downwarped ("j"). This warping may have developed when a buried ice block melted out below and deformed the adjacent strata while they were saturated. After the block melted the resulting basin filled with horizontal interbeds of unfossiliferous fine sand and silty clay ("k"). The upper 50 cm of the entire deposit has been reworked by waves ("l").

The presence of large volumes of poorly sorted gravels recurring throughout the exposure suggests that the sediment complex developed adjacent to an ice mass. The rapid grading to fine sand suggests that much of the sediment was deposited subaqueously. This idea is substantiated

Figure 3-15 Pitwall exposure five kilometers west of Godbout

Figure 3-16 Poorly stratified, coarse-grained outwash, Daigle outwash plain (map unit 3c). Photo was taken about ½ km south of the Daigle moraine.

by the bedding in the kettle; fines are more likely to settle out into horizontal bands in a subaqueous environment than in a subaerial one, where bedding trends are more closely related to the topography of the depression. In this interpretation, gravelly zones such as "j" may represent flow till which sloughed down from the ice.

3. Island Lake

A third small ice contact deposit, possibly a kame, is located 30 m west of Island Lake (49°18'N; 67°50'W) at an elevation of 148 m (i.e. above marine limit). The deposit consists of contorted and faulted strata of soft brown and grey sands with a few lenses of subangular cobbles.

Eskers

Eskers are rare on the Laurentide massif, although they are abundant on the Lake Plateau to the north (Hare, 1959). In the field area, one short sinuous ridge was observed in the west Rivière aux Rochers valley along the road to Gagnon at milepost 40. Other ridges in similar valley positions were noted on air photos of the region beyond the area which was examined on the ground, and esker-like ridges have also been reported in the Moisie River system north of the field area (e.g. Hogan, 1971). The paucity of eskers and the restricted locations in which they are found suggest that during the last glacial stages ice was actively retreating rather than stagnating, and that meltwater was free to drain down the natural slope of the land in pre-existing channels.

Outwash

Proglacial features are more widespread and less puzzling than the ice contact deposits. A small, steeply-dipping, sharply-defined outwash fan lies in front of the Loop moraine (49°16'N; 67°42'W). Ice contact deposits probably underlie the gravels south of the Valley Front moraines between Lac Pentecôte and Port Cartier. In each case, however, most of the gravelly material fronting these moraines was carried from more remote sources by meltwater streams which breached the morainic ridges. Outwash was deposited all along the melt channels, but especially in front of the moraines where, no longer confined, the streams rapidly lost competence. The result is a set of broad, gently convex outwash fans. Shallow borrow pits show that the Pentecôte-Dupont, Riverin and Vachon River outwash consist of rounded, oblate, poorly bedded, cobbly gravel.

Outwash associated with the Daigle moraine covers a much larger area, forming an outwash plain which slopes from 138 m, where it covers the lower flanks of the moraine, to 128 m five kilometres to the south. Gravel pits show that the deposits are at least six metres deep in the central part, but thin out towards the sides. The deposit consists primarily of granitic, rounded, cobbly gravel and sand in southward dipping beds (Figure 3-16). Most of the lower bedding surfaces are erosional. High-angle avalanche beds, involuted sand lenses, and imbricated pebble and cobble rows are common large-scale sedimentary structures. No consistent vertical textural change was recognized in the field. The longitudinal or cross-sectional change however is very pronounced. In front of the moraine near the breach-point, the outwash consists of abraded boulders and large cobbles, separated by a poorly-sorted unstratified sandy matrix. There does not appear to be any grading or interfingering with the till, which suggests that this outwash is proglacial rather than ice contact material. This outwash rapidly grades radially into stratified pebbly gravel. Poor sorting and rapid nonsystematic structural changes suggest a rapid loss of competence, either from seasonal changes in glacial regime or from the braiding of shallow channels. At the extremities of the plain the surface material has the size and sorting characteristics of beach deposits and a local base level must have existed at this elevation (128 m). Because prograding beach ridges begin at the outer slope break of the outwash plain, this line has been taken as the marine limit for the Sept-Iles area.

The outwash deposits can be traced back through the break in the Daigle moraine into a bedrock channel in which the present Ruisseau Daigle, flowing northwards towards the Moisie River, has cut through at least 67 m of this outwash. Erosion and downcutting have dissected the deposit, but the highest kettle-holed remnants of the original outwash still stand at an elevation of 130 m.

Many rivers, particularly those flowing in preglacial channels, carried vast quantities of sediment-laden meltwater. The presence of outwash within these melt channels can be recognized by the small kettle holes which are prevalent on upper terraces, by flattened valley floors occupied by grossly underfit streams, and indirectly by anomalous stream flow reversals which occur where thick outwash deposits have completely plugged the normal direction of drainage as indicated by the continuity of the original rock-walled valleys.

Above the marine limit the highest stream terraces usually consist of bouldery kame deposits, while lower levels are composed of successively finer-textured and better sorted outwash gravels, and gradually grade into recent, non-glacial alluvial sand and gravel point bars.

4. SURFICIAL MATERIALS PART B: DEPOSITS ASSOCIATED WITH THE MARINE REGRESSION

4.1 Introductory Statement: Facies Distinctions

Three distinctive types of deposits are associated with the marine episode in this area. They represent different sedimentary environments, and can be recognized by textural and structural differences.

(1) Offshore deposits: very poorly sorted, fine-grained material sedimented in deep water marine and estuarine environments.

(2) Nearshore deposits: fine-grained sands which have been fairly well sorted by tractive currents; they exhibit ripple drift laminations within delta foreset beds.

(3) Littoral deposits: oxidized, well-sorted, medium to coarse brown sand in subhorizontal strata.

The stratigraphic record, as observed along the North Shore, is an offlap sequence: deep water clays are overlain by nearshore deposits, which in turn are overlain by littoral sand.

The various facies and their structural sub-units are described in the following sections.

4.2 Offshore Deposits

Facies definition and distribution

Marine clays and silts underlie much of the coastal plain. They were deposited as the offshore facies of the fluvio-marine sequence in the estuaries, and along the coast as deep water sediments between the main deltas. The materials in this facies are characterized by their silty texture and very poor sorting. They also have behavioural properties which differ from the nearshore and shore facies.

The clays are at the surface north of the Baie des Sept-Iles, but in most other places they are only seen in vertical exposures along the Moisie, Hall, Pentecôte, Petite Trinité, St.-Nicholas and Mistassini Rivers or in railway cuttings. Some of the abandoned coastal cliffs have also been cut into the marine sediments, exposing clay facies near Sept-Iles, Port-Cartier, Ilets-Caribou and Franquelin.

Stratigraphically, borehole data indicates that most of the offshore deposits directly overlie bedrock. Beneath part of the Sept-Iles townsite, however, clays are underlain by thin lenses of "gravel" and in the Baie St.-Nicholas area, the clays are separated from bedrock by a bed of fine sand.

The greatest reported thickness of these sediments is in the Moisie Valley at QNS&L Milepost 19.3, where 236 metres of offshore clays were encountered (Table 4-1). At Rivière aux Foins (near Sept-Iles) the clays extend from sea level to at least -58 metres (QDNR, 1973). Elsewhere they are thinner. Along the Baie St. Nicholas fiord, the bedrock (at -34 m) is overlain by about 42 metres of clay.

Generally, the clays are unconformably overlain by thick accumulations of nearshore and littoral sediment.

General appearance

When dry, the deep water sediment appears to be a stiff, grey, brittle silty clay, which breaks with a conchoidal or hackly fracture. The dry surface is covered by fissures ranging from hairline fractures to a network of wide cracks which give the clays a blocky outer structure. Cracks up to 1.5 cm wide were observed in outcrop along the north part of

Table 4-1 Quebec North Shore and Labrador Railway Borehole Log at Milepost 19.3*

Depth (m)	Elevation (m ASL)	Description
0-1	60-59	topsoil
1-4	59-56	medium to fine brown sand
4-12	56-48	grey stratified silty clay
12-15	48-45	grey clay with silt and sand strata
15-22	45-38	grey stratified silty clay
22-24	38-36	sand and gravel
24-31	36-29	grey clay with sand and gravel strata LL = 42% PL = 21% W = 38%
31-242	29--182	easy advance (clay)
242-243	-182--183	obstruction, presumably bedrock

* from R.W. Pryer, 1970, writ. com.

the Baie des Sept-Iles. Field samples indicate that there is a four per cent shrinkage by volume as the clays dry. Skempton and Northey (1952) suggested that the fissures develop as a result of syneresis, a "colloidal process whereby the particles draw themselves together under the action of attractive forces and expel some of the pore water".

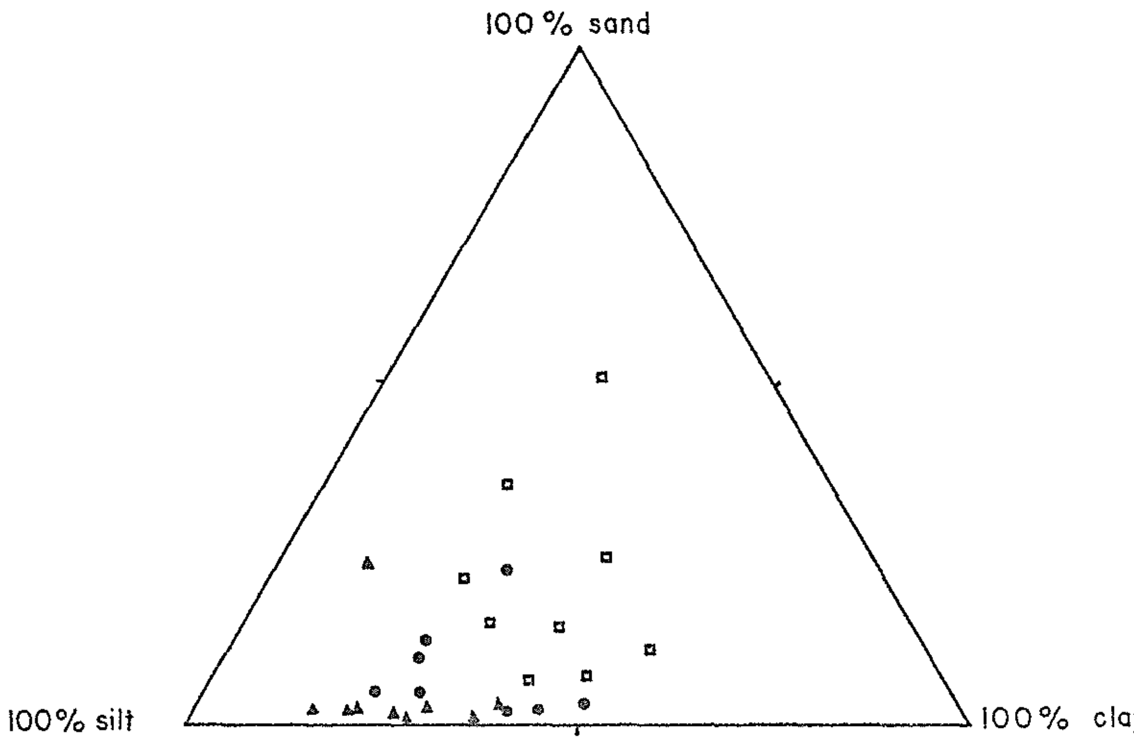
On wet surfaces, and in the subsoil, the clays are soft, blue-grey, and either very sticky or slippery.

Texture

The deposits are fine-grained, the texture composition of 17 field samples being 15% sand, 56% silt and 34% clay (Figure 4-1). The mean grain size is a fine silt ($\phi = 7.6$; 0.005 mm), but there are small quantities of sand and substantial amounts of clay-sized ($<$ .002 mm) material. The clay percentages vary from one locality to another, as can be seen from the grain size curves (Appendix D) and Figure 4-1. In each case, however, there are sufficient clay-sized materials to influence the behaviour of the sediments. The materials are almost free of pebbles, which suggests that the deposits represent true marine, rather than glacio-marine conditions. Possible exceptions are at Ilets Caribou, where a few pebbles were found within the clays, and at a site west of Lac Pentecôte where fine slivers of rock constituted part of the deposit.

The sediment is very poorly sorted ($\sigma = 3.4$). This may be a result of deposition by flocculation in a marine or brackish environment. The clays are also slightly positively skewed. Berry and Jorgensen (1971) state that the skew is caused by a deficiency of coarse material which cannot be transported into quiet marine environments, rather than by an abundance of fines.

Figure 4-1 Grain size distribution for offshore sediment



◽ banded sediment average: 21 % sand 42 % silt 37 % clay

● massive sediment average: 8 % sand 61 % silt 31 % clay

▲ borehole data from Moisie River (QNS & L RR files)

Banded and massive units

As with the Champlain Sea clays (Karrow, 1961) the offshore deposits of the Quebec North Shore can be divided into two main sediment types: a massive unit, which is homogeneous throughout and which is situated beyond the zone of influence of river-generated currents; and a banded unit (Figure 4-2; 4-3) whose distribution is related to areas susceptible to fluctuations in river regimes (e.g. delta margins).

The banded unit is texturally stratified into cosets of clayey silt one to eight centimetres thick (the average thickness is two centimetres) sharply separated by grey sand partings several millimetres thick. Bedding is usually nearly horizontal but southerly inclinations up to 12° were measured in the field along the QNS&L railway. The cause of the changes in bedding angle may be related to scouring and major disruptions in flow regime. The effect of these erosional truncations, combined with occasional sandy lenses, produces the condition where locally excessive pore water pressures develop during periods of heavy rainfall.

Within the banded unit the silty clay is neither laminated nor graded. The sand partings are also ungraded. The sediment comprising the banded unit may have been transported by turbidity currents which originated either in the delta foreset environment or as cold freshwater bottom currents. The distribution of these sediments is definitely geographically related to estuarine conditions which existed in the drowned preglacial valleys in postglacial time. Externally the unit resembles varves in that there are sand layers alternating with distinct silty bands. Upon examination of the textural characteristics, however, the finer bands are too coarse to fit the zone of winter varves (zone 1) on Banerjee's varve diagram (Figure 4-4) but at the same time lack the structures associated

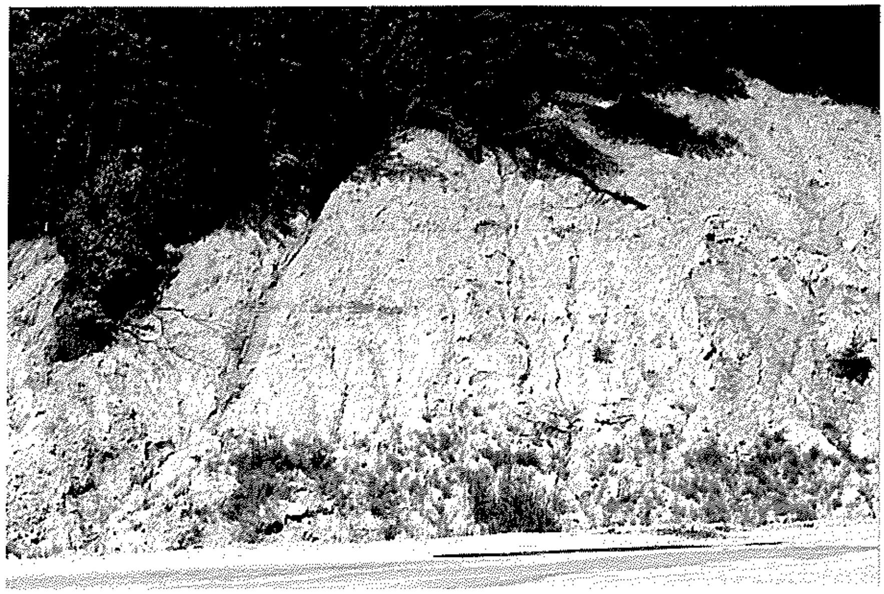
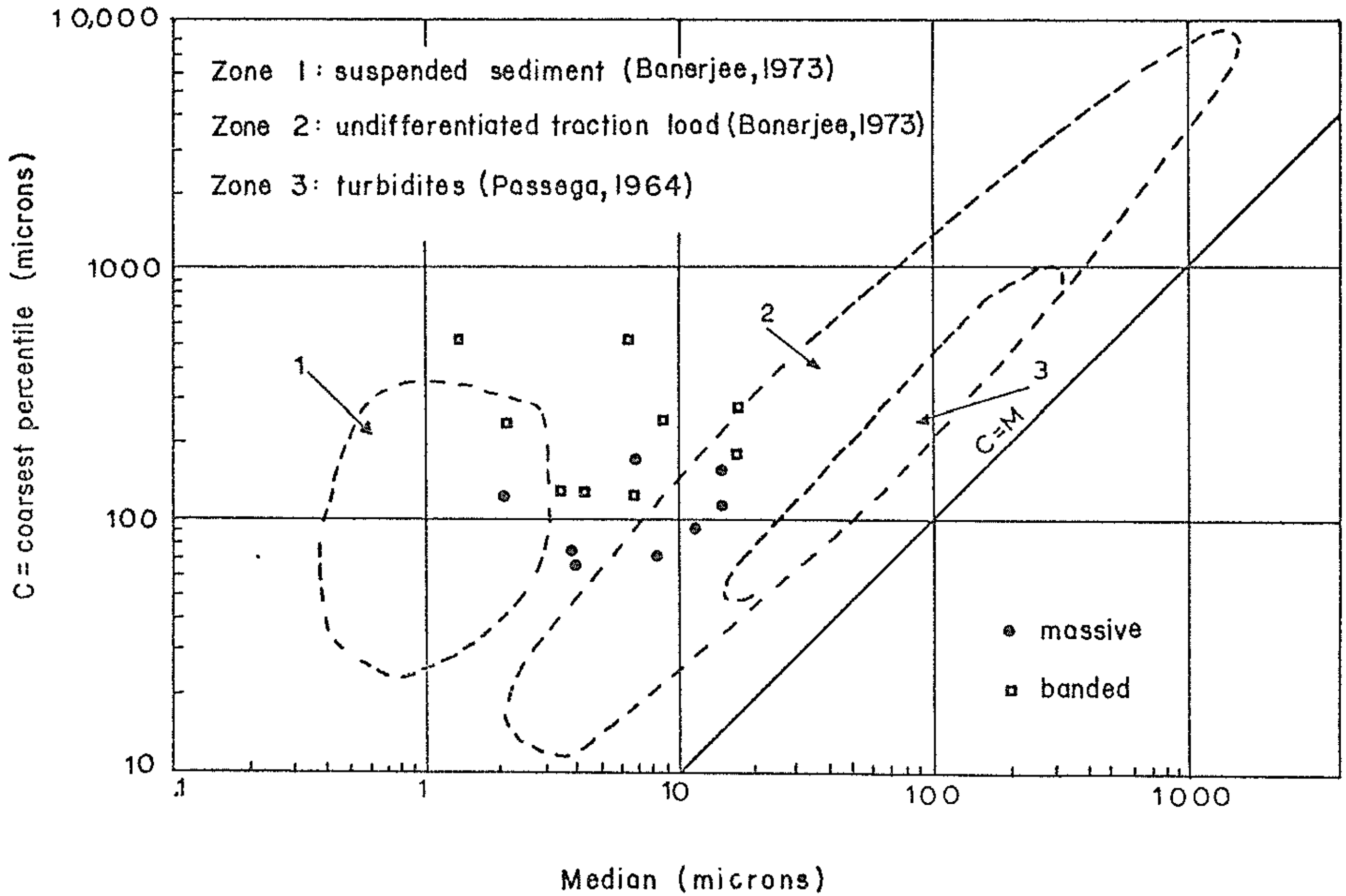


Figure 4-2 Banded silty clay (unit 4c) typical of offshore marine sediment. Photo shows a typical exposure at Rivière Vachon, where surface weathering makes banding difficult to see.

Figure 4-3 Close-up of bands exposed along rills near milepost 9, QNS&L RR. Bands are about three centimetres thick.

Figure 4-4 CM diagram (after Passega, 1964) for fine-grained sediment



with his summer layers (zone 2). It is suggested here that both the sand and the silty clay are deposited as a "summer" layer. The coarse (sandy) load may have been transported at the head and base of tractive bottom currents and deposited in deep water when the currents lost velocity. Because of the salinity of the marine environment, the finer particles probably tended to flocculate and therefore both the fine part of the "summer" varve and the "winter" clay sedimented as one unit[1]. The absence of laminae and stratification is also attributed to flocculation in saline water. Fraser (1929) demonstrated experimentally that sedimentary structures do not develop once salinity exceeds four grams per litre.

The clean break between the coarse sandy band and the finer material may reflect a time lag in the settling of the suspended load. Kuenen (1951) has calculated that when suspended material from the Greenland ice sheet enters salt water, the sediment tends to rise to the surface and spread out because the density of fresh water with suspended load (1.007 g/cc) is much less than the density of salt water (= 1.028 g/cc). If similar conditions once prevailed along the North Shore, there would be a short delay between the deposition of the coarse sand by tractive bottom currents and settlement of the flocculated suspended load.

When hydrometer analyses of dispersed samples were being run, particles settled out in a graded bed with minor laminations, which was eventually topped by a distinct dark layer. This observation indicates

[1]Examination of the grain size curves of those samples which come from well defined banded units, such as those along the QNS&L (77-44 and 69-30) and Arnaud railways (74-26) reveals that the textural distribution of the fine sands is bimodal. The coarser mode has a median grain size which plots in the varve-turbidite zone on Banerjee's diagram (Banerjee, 1973), and the finer segment plots near his zone of winter varves. Thus, the textural components of both winter and summer varves are present, but they were sedimented together.

that, had the particles originally settled in a freshwater environment, they would have had the same textural and structural characteristics as the glacial varves from lakes Barlow-Ojibway and Iroquois as determined by Banerjee (1973). They also would have shown the graded zone ("a"), laminated layer ("d") and pelitic layer ("e") of the ideal turbidite sequence as prosposed by Bouma (1962). The middle of his sequence, characterized by sandy laminations ("b") and current ripples ("c") would still be absent because of the general absence of coarse (sand-sized) particles.

The massive unit is texturally similar to the finer part of the banded unit. The meansize is similar, but the coarsest material is absent. This unit was probably deposited as a flocculated uniform suspension in deep water beyond the influence of tractive currents.

Mineralogy

Six clay samples were selected for X-ray analysis. These were chosen to reflect possible differences which might arise from differing sedimentary environments (massive vs. banded), from different underlying bedrock types, and from sites with and without landslides. The mineralogies of three size fractions were determined by X-ray diffraction using Cu K_α radiation. The results are summarized in Table 4-2 and the traces of powder, heated and glycolated samples are included in Appendix C. On the basis of this limited number of analyses several preliminary conclusions can be drawn.

1. From the table it is apparent that the marine sediments are dominated by non-clay minerals. Quartz and feldspar, particularly plagioclase, are

Table 4-2 The Mineralogy of Offshore Clay

Location	Sample # & Fraction	Sediment Type	Nearby Bedrock	Occurrence of Landslides	General Nature of Diffraction Curve	Dominant Mineral Peaks in Order of Decreasing Magnitude			Other Minerals Present
Sept-Iles	28; < 63µ	massive	gabbro-anorthosite	+	distinct	q	fel		am, mi, kl, tr. ca, mag, py
	28; < 5µ				distinct	mi	it	fel	am, pn, ch
	28; < 2µ				fairly distinct peaks	it	fel	q	ch, am, py, tr. mm
QNS&L Mile 10	44; < 63µ	banded	gneiss	+	low peaks	pg	q	gt	mi, am
	44; < 5µ				low peaks	fel	mi		gt, am
	44; < 2µ					it	ch	mx	fel, q, am, poss. mm
Port-Cartier	56; < 63µ	banded	gabbro	+		pg	mi	q	ch-mi, gt, py, ca
	56; < 5µ					mi-it	q		pn, fel, am, ha
	56; < 2µ					it			q, fel, mx, ca
Pentecôte	42; < 63µ	banded	gabbro	–	very high Qz peak	q	fel		gt, am, ch, py, ov
	42; < 5µ					mi	fel	mx	q, ch, am, ov
	42; < 2µ				no strong peaks	it	ch	vm	q, fel, mi, kl
Ilets-Caribou	81; < 63µ	banded	gneiss	–	peaks distinct	fel	q		ch, ov, mi, gt, tr. ca
	81; < 5µ				poor	mi-it	fel		–
	81; < 2µ				no peaks.	mx			tr. fel, ch, kl
Baie St. Nicholas	89; < 63µ	massive	gneiss	+	peaks very distinct	fel	mi	q	ov, py, pn
	89; < 5µ				distinct peaks	mi-it	am	ch	fel, gt
	89; < 2µ				low peaks	it	ch	mx	fel, gt, tr. am, ha?

Code

am	amphibole
ca	calcite
ch	chlorite
fel	feldspar
gt	garnet
ha	halloysite
it	illite
kl	kaolinite
mag	magnetite
mi	mica
mm	montmorillonite
mx	mixed-layer
ov	olivine
pg	plagioclase
pn	pyroxene
py	pyrite
q	quartz
vm	vermiculite

the most abundant minerals. Lesser amounts of mica and amphibole or pyroxene are also present. The clay minerals which appear are mica-illite, chlorite, and mixed layer minerals. Carbonate minerals are absent or present in trace amounts only.

2. The mineralogy of the clays is dependent on grain size and therefore, texture should be a good indicator of behaviour (cf Figure 4-6, p. 101 (W_L vs. % clay)). As particle size decreases clay minerals become more important. Quartz and feldspar are the main minerals in the silt sizes. In the < .005 mm range there is a sharp increase in micas; feldspars are still important components but quartz content declines. In the <.002 mm fraction mica-illite and chlorite are the principal minerals, and traces of montomorillonite (?) are also present.

3. The X-ray diffraction peaks of the marine clays are not well defined. The poor definition may be due in part to the scannning speed,[1] but to some extent it indicates the presence of amorphous or poorly crystalline material in the finest fractions. It has been shown that amorphous iron and aluminum are present in the soil profile in the Sept-Iles area and that they are created by weathering of ferromagnesian minerals in the soil (Moore, 1976). If amorphous material is also present in the marine sediments, as suggested here, it is possible that it is derived from weathering products of ultramafic rock types, for the X-ray trace of the fines in the mafic Dupont till (Appendix C) is extremely diffuse in the <.002 mm fraction, while that of the Mile 12 (granitic) till is fairly clear. McKyes, Sethi and Yong (1974) have found that amorphous oxides of silicon and iron are present in samples of clay from St. Vallier and St. Louis

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[1] Samples from the Gaspé (south shore) with the same preparation and scanning speed produced distinct peaks (J. Locat, personal communication).

(St. Lawrence lowlands), and that the amorphous component makes up 11-12% of the weight.

4. The mineralogy of the marine sediments is very similar to that of the fine fraction of the till, as might be expected from material which originated as rock flour. This observation agrees with the findings of Allen and Johns (1960) who concluded that "the source of the material has a greater effect on the mineral composition than the environment in which deposition took place" (page 83).

5. At each site there is a contribution from both major rock types, and the mineralogical assemblages cannot be directly related to underlying rock type.

6. Similarly, there is no obvious difference in the mineralogy of samples from sites with landslides and those without. Although the small number of samples precludes any firm conclusion, this suggests that the presence of slides is related either to trace minerals, such as montmorillonite and vermiculite, or to external factors such as hydrologic conditions.

7. The mineral assemblage presented here is similar to results obtained by other workers in the same area. Quigley (1968) reported abundant quartz, feldspar and amphibole, along with illite and chlorite in the Toulnustouc clays; and Yong and Warkentin (1966, 72-74) have found that mica was the dominant mineral in the "Seven Islands" clay, although quartz and feldspar were also abundant, and chlorite and amphibole were present.

The marine sediments are similar in mineralogy to Leda clays in the St. Lawrence Lowlands, where plagioclase, quartz and amphibole are abundant in the silt range and feldspar, illite, hydrous mica and chlorite are important in the clay sizes. However, in the Lowlands, the amount of illite appears to be greater than the samples run from the North Shore, and vermiculite and montmorillonite are also present (e.g. Allen and Johns, 1960). Another difference is that the Paleozoic rocks contribute carbonate minerals to the clays in the Lowlands, and where there is a black shale, organic gels have been reported. The presence of more swelling clay and organic gels in the Lowlands might explain some of the differences in index properties and behaviour.

The mineralogical composition affects both index and behavioural characteristics, which are discussed below. First of all, because of the large percentage of non-clay minerals, the clays should be expected to exhibit, in part at least, brittle behaviour, even though most studies in the past have explained behaviour using a pure illitic clay as a model. Secondly, the mineralogy affects the shear strength because it determines the type of interparticle bond which can be formed: Cabrera and Smalley (1973) have proposed that quick clay behaviour is caused by the breakage of short range bonds associated with non-clay minerals. As soon as a small displacement occurs, the strength of the bonds involved drops to zero. Thirdly, mineralogy also determines the amount of water that particles can absorb (Berry and Jorgensen, 1971), and to some extent it affects the chemistry of the pore water (Berry and Jorgensen relate sensitivity to the presence of monovalent ions which have gone into solution in the pore water). Fourthly, the presence of amorphous minerals can also affect the behaviour of marine clays. According to Moum, Løken and Torrance (1971) amorphous iron and aluminum precipitate at particle contacts, making brittle, cemented, over-strengthened bonds. The presence of these bonds has been confirmed in Toulnustouc clays (Quigley, 1968) and X-ray traces suggest that amorphous materials could be present here.

Pore water

Natural water contents from boreholes and field samples average 38% of the dry soil weight (Figure 4-5; Table 4-3). Field values range between 16% and 64%, the highest being derived from landslide sites at Sept-Iles. Old exposed surfaces of marine sediments commonly have a desiccated outer crust. Along bluff exposures this desiccated layer is limited to the outside 20 cm, but borehole records indicate that the crust is at least three metres thick in some places. Aside from this upper zone there is no systematic change in water content with depth in borehole samples. Water contents are especially variable in banded clays. The high water contents in cores from these sediments may relate to confined sand lenses and disrupted bedding planes, where excessive pore water pressures could develop.

The pore water in these sediments is probably "free" water; i.e. it is not "bound" to soil particles by a diffuse ion layer because most of the particles are uncharged, non-clay minerals. Therefore, although the water content is not generally as high as values obtained for Leda clay in the St. Lawrence Lowland, the water content may still be significantly high.

The salinity of the pore water is apparently low. Salt contents were not determined during the field study but nine samples between milepost 18.5 and milepost 25 of the QNS&L railway were analysed at the National Research Council and Purdue University (unpublished data in QNS&L files). Sodium chloride contents in the pore water ranged between 0.8 g/1 and 4.6 g/1, and averaged 1.5 g/1. These values are similar to salt contents in leached Leda clays, which are commonly 1-2 g/1 (Penner, 1963). If the salinity of the pore water at one time approached that of sea water, then it would appear that the North Shore clays have also been leached.

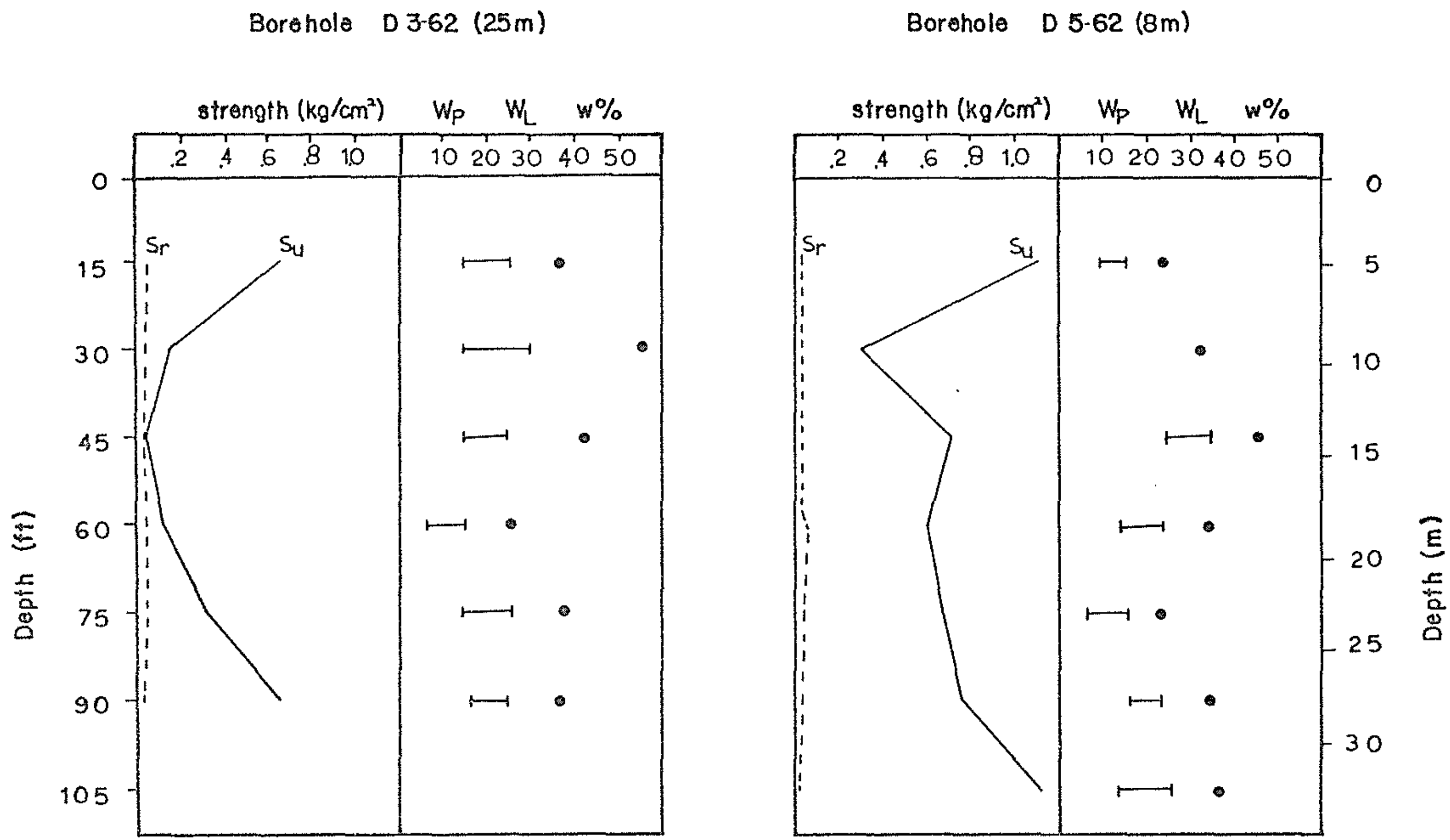

Figure 4-5 Index and strength properties of clays at Baie St. Nicholas, QDNR dossier 3993-22

Table 4-3 Index Properties of offshore marine clays based on 1974 field data

Sample Reference	Texture(%) sa	si	cl	Index Properties w(%)	W_L	W_P	IP	IL	Act	Density(g/cc) bulk	dry	Soil Properties Class^{n}	pH	HCl react	Penetration resistance + Shear Strength(kg/cm^2) surface or subsurface	Pocket Pen. qu	Cone Pen. qu	Vane S	Remoulded Sr	Sensitivit[y] Vane Field	Bjerr[um] sca[le]
74-5 Moisie gully	5	73	22	26.8	23	20	3	2.3	.14	1.98	1.56	ML	8 +	0	ss	1.0		0.43			64
74-44 Mile 10	15	46	39	39.1	39	18	21	1.0	.54	1.92	1.37	Cl-CL	7.0	0	ss	1.48		0.53	0.15	3.5	8
															sandy	2.00					
74-46 Sept-Iles	2	54	44	46.3	35	21	14	1.8	.32	1.92	1.31	Cl-CL	7.5	0	ss	0.32		0.15			30
74-27 Sept-Iles slide#4	3	47	50	64.5						1.76	1.24				ss	0.40	3.48	0.24	0.01	24	
slide #5															s. dry	2.40	4.20				
															s. ss	0.16	3.12	0.13			
															fiss s	1.05	4.30	0.22			
															fiss s	>5.0	2.37	1.06			
74- Sept-Iles Baie															ss	1.58		0.30			
74-26 Rapides	7	46	47	55.4	51	17	34	1.1	.72			CH	7.0	0	ss		2.75	0.37			[illegible]
74-56 Pt. Cartier W	2	58	40	32.4	31	19	12	1.1	.30	2.00	1.52	CL	8.0	0	ss	1.38		0.48	0.08	6	[illegible]
Little Vachon															fiss s	2.71		0.59			
Pelletizer					27	17	10					CL-ML									
74-42 Pentecôte W.	11	35	54	37.4	50	23	27	0.5	.50	1.72	1.25	Cl-CH	8.5	0	ss	1.62		0.79			[illegible]
74-58 Pet.Riv.Trinité	52	22	26	29.6	25	16	9	1.5	.35			CL	7.0	slight							[illegible]
74-81 Ilets Caribou	25	34	41	31.8	28	17	11	1.4	.27	1.99	1.60	CL	7!	0	ss	3.00		1.16	0.19	6	[illegible]
74-82 Ilets Caribou				24.6																	
74-90 St Nicholas Upper	24	48	28	29.7	22	18	4	3.0	.14	1.37	1.05	ML	7.5	shells only							>[illegible]
74-89 St Nicholas Lower	10	65	25	31.1	24	18	6	2.2	.24	1.95	1.50	CL	8.0	0	ss	0.23		0.25	0.01	25	6[illegible]
74-94 Franquelin	16	53	31	22.1	28	18	10	0.4	.32	2.13	1.63	CL	7.0	weak	ss	1.66		0.61	0.08	7.5	[illegible]

Rosenqvist (1953) and Bjerrum (1954) found that low salt contents in Norwegian marine clays were associated with high sensitivity, and Leibling and Kerr (1965) mention the same relationship for clays in the St. Lawrence Lowland. They claim that when clays are sedimented with a high electrolyte (salt content ~ 30 g/l) they are capable of holding a large quantity of water because a thick water film is bound to each soil grain by an electric double layer. When salts are leached out, however, the effect of the double layer is reduced, so that water is no longer bound to particles but forms free water in the pore spaces. When leached, the system continues to exist in a metastable (i.e. potentially unstable) condition until disturbed, but upon remolding pore water is liberated and the clay turns into a liquid. On this basis, the low salt contents in the North Shore samples suggest that the marine clays are highly sensitive, and that this sensitivity may be due to leaching. However, other workers refute this explanation and state that the situation is more complex. Soderblom (1969) for example says "there is no correlation between salt content and sensitivity" for Norwegian clays and claimed that organic and inorganic dispersants were equally important, and Penner (1965) states that "at low salt concentrations a high sensitivity cannot be automatically assumed."[1]

Index properties

In almost every case, natural water contents exceed liquid limit values (Figure 4-5; Table 4-3). For the field (near-surface) samples,

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[1] He claims that in the low salt content range it is the presence of monovalent cations, which increase inter-particle repulsion, that weakens the soil structure and therefore increases the sensitivity. He states that divalent cations reduce the repulsion. However, Moum, Løken and Torrance (1971) claim that it is the divalent cations, Ca^{++} and Mg^{++}, which are associated with sensitive conditions.

which may be in a partially desiccated zone, water contents are only slightly higher than the liquid limits, but borehole records show that the difference is greater in the subsurface. The low values of the liquid limit relative to natural water contents may be a reflection of leaching. According to Rosenqvist (1953) soils leached of electrolytes or with initially low electrolyte content cannot bind water to the soil particles. Therefore, the water content at which these soils will behave as a liquid, i.e. the liquid limit, is much lower.

Within the field samples there is a range of liquid limits. A plot of this limit vs. clay content (Figure 4-6) shows that the limit is directly related to the amount of clay in the sample. Where the clay content is low, the liquid limit is also low because there are few charged particles which can adsorb ionized water. Where the amount of (charged) clay particles is greater, however, more water particles can be adsorbed and consequently the liquid limit is higher. This assumes that as the percentage of clay-sized material increases, the percentage of clay minerals also probably increases.

The plastic limit and plasticity index are fairly low, and samples plot within the CI-CL zone just above the "A" line on the Casagrande chart (Figure 4-7). Similar values were obtained by Conlon (1966) in the Toulnustouc River area. North Shore sample values fall along the same line on the plasticity chart as the glacially derived clays in the St. Lawrence Lowland, but the latter are in the CH position of the chart.

The low plasticity, rare for materials with high clay contents generally, suggests that the long-range type of interparticle bond (terminology of Cabrera and Smalley, 1973) is not generally present. The activity of the sample, defined by Skempton (1950) as PI/%<2μ, is also very low (Figure 4-8), which further supports the other evidence that the

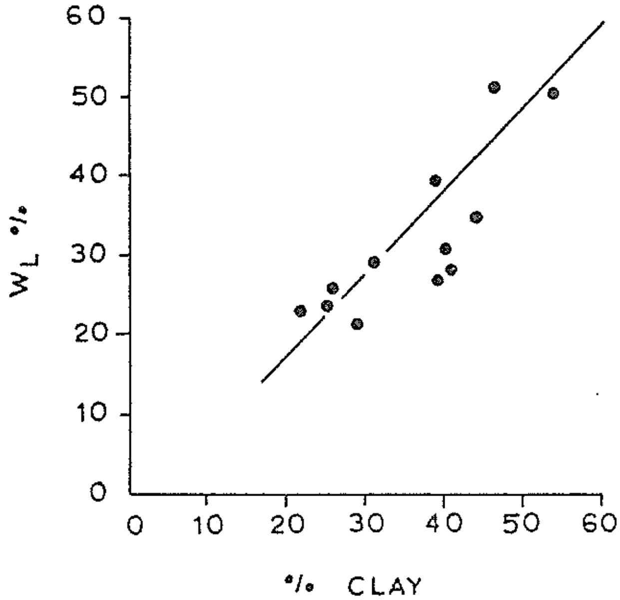
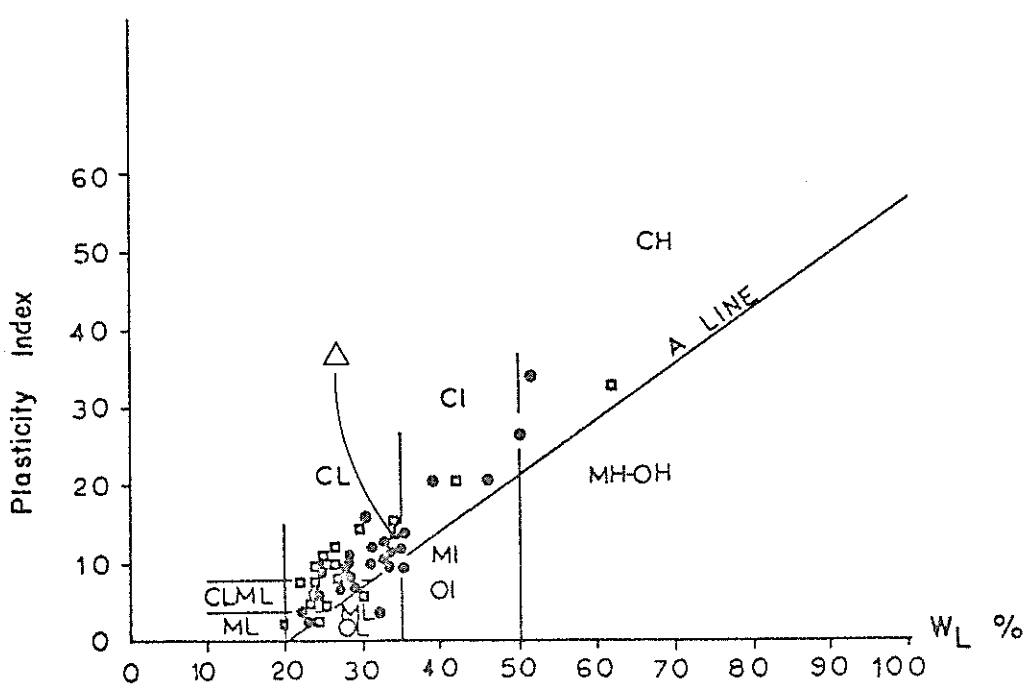


Figure 4-6

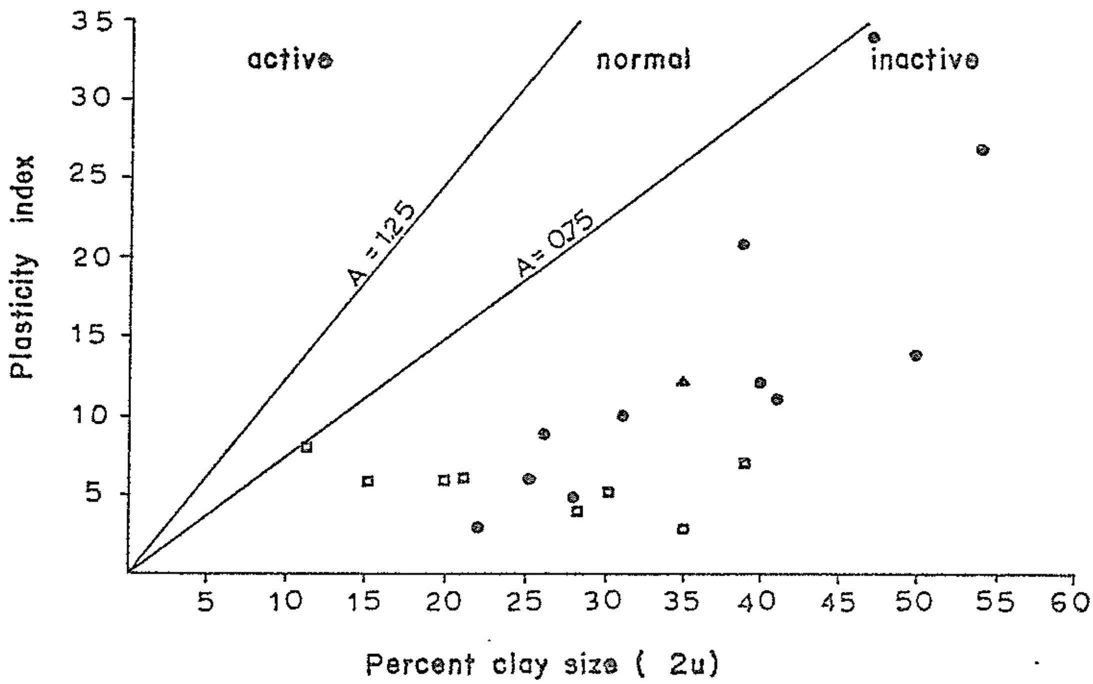
Percent clay – Liquid limit relationship for North Shore clays

Figure 4-7 Soil classification and Plasticity index chart



• field data ▫ borehole data ▲QNS&L RR data (average of 774 samples)

Figure 4-8 Activity chart



• field samples, ▫ borehole data, ▲ QNS&L RR data (av. of 700 values) clay-sized fraction has few "active" clay minerals.

Structure of mineral aggregates

No studies were conducted to determine the microstructural framework of the sediment. I suggest that the framework is fairly open because:

1. Water contents are high and exceed the liquid limits even in stable areas. This suggests that there is a high volume of voids.
2. The marine depositional environment and the resulting flocculation of clays produce open frameworks.
3. Measured preconsolidation pressures (Tables 4-4 and 4-5) are less than those necessary to destroy open frameworks. Quigley and Thompson (1966) found that a stress of 64 kg/cm^2 was required to destroy the structure of the cemented Toulnustouc clays.
4. The bulk density is very low compared to the specific gravity of the individual mineral components (Table 4-3).
5. The clays have properties similar to other clays with open frameworks, whether they be cardhouse structures (Tan, 1957) or aggregate chains (Pusch, 1966).

Consolidation characteristics

The clays in the Sept-Iles area are slightly to moderately over-consolidated (Woods *et al.* 1959), and representative values of the pre-consolidation pressure obtained from borehole samples at various localities are tabulated below. Conlon (1966) claims that high preconsolidation (Pc) values are caused by bond cementation for the case of the Toulnustouc clays. For other sites listed below, however, the Pc value is only slightly greater than the weight of the present overburden, so that the Pc values may simply reflect the erosion of the upper parts of the deposits.

Table 4-4 Preconsolidation pressures on samples of marine clay

Location	Pc (Kg/cm^2)	Reference
Moisie River	4.3 - 6.6	QDNR (1974)
	2.5 - 4.5	Pryer and Woods (1959)
Baie St. Nicholas	1.3 - 2.0	QDNR (1962)
Toulnustouc River	12.0	Conlon (1966)

The shapes of the "e log P" curves vary from one site to another. At Baie St. Nicholas the slopes of most of the curves are very low, and they indicate either that increased pressure produces continuous plastic deformation characteristic of normal clays or remoulded sensitive clays (interpretation based on Yong and Warkentin, 1966, Figure 8-29, p. 217), or that the samples were disturbed. The other curves at Baie St. Nicholas and at Moisie indicate that the clay structure is capable of withstanding higher initial stresses, with only minor rearrangement of weaker bonds, but that once sufficient pressure is applied the framework completely collapses. This brittle type of behaviour is characteristic of clays having cemented bonds, or materials in which the main interparticle contacts are Vander Waals-type short range bonds. Both these situations are applicable to the clays along the North Shore. It has already been mentioned that nearby clays are cemented with iron and aluminum precipitates, and it has been previously shown that inactive (non-clay) minerals comprise most of the marine sediment.

Shear strength

Shear strengths were determined in the field using Geonor and Pilcon shear vanes, and with proving ring and pocket penetrometers (which theoretically measure unconfined compressive strengths (qu)). Where tests were performed on desiccated fissured surfaces, shear strengths and penetration values exceeded 5.0 kg/cm^2, the limits of the instruments. Below the weathered crust shear strength values were low - always less than 1.0 kg/cm^2 and generally less than 0.5 kg/cm^2.

Values obtained at depth from borehole records were also generally small. Iron Ore Company borehole reports show that shear strength generally increases with depth below the Sept-Iles townsite, a trend that can be expected from normal compaction. This is not true for records from the Moisie River bridge area or from Baie St. Nicholas (Table 4-5 and Figure 4-5). Vane tests from boreholes at these sites indicate:

1. there is no systematic change in strength below the surface hardening which has a maximum depth of two metres.
2. there are planes of weakness within more competent clays.

Shear resistances from borehole reports ranged from 0.05 kg/cm^2 to 1.17 kg/cm^2. Pryer and Woods (1959) noted that the lowest values were derived from sites with the siltiest material and those with lowest plasticity.

Shearing resistance in massive clays appears to be isotropic. This was not the case with the banded sediments, however. In field tests near Lac des Rapides the dry, banded sediments have vertical penetration resistance of 1-3 kg/cm^2 but horizontal resistance is near 1.2 kg/cm^2. The difference is probably caused by the sand partings which act as horizontal planes of weakness. Similar anisotropy has been noted by Gardmeister (1967), where vertical strength was about 15% greater than horizontal strengths in banded sediments along the Saimaa Canal in Finland. By analogy, where borehole vane tests were performed in banded sediments, the shear strength values which were obtained may similarly overestimate the horizontal shear resistance at failure.

	Sample #	Desc.	Depth (BSL) ft (m)	% sand	silt	clay	w%	w_L	w_P	PI	Act.	dens bulk g/cc	shear strength kg/cm^2	rem.	sens.	Pc kg/m^2
Borehole #1	2824	silty clay with sand	10 (3)	24	65	11	37	22	14	8	0.73	1.70	.34	0.09	4	4.8
	3184		50 (15)	1	64	35	40	20	16	3	0.09	1.79	.61	0.03	20	4.3
	3185	silty clay	60 (18)	1	71	28	46	24	19	4	0.14	1.80	1.06	0.05	21	4.4
	3186		70 (21)	2	83	15	47	25	19	6	0.40	1.79	0.89	0.05	18	6.1
	3187	silty clay	80 (25)	2	78	20	49	30	24	6	0.30	1.73	1.05	0.02	52	6.0
Borehole #2	3191	silty and clay	60 (18)	2	72	26	47	24	-	-	-	1.76	0.86	0.025	34	5.0
	3193	silty and clay	70 (21)	2	59	39	49	27	22	7	0.18	1.73	0.90	0.06	15	6.6
	3194	silt and clay	40 (27)	2	77	21	46	24	18	6	0.28	1.74	0.55	0.02	28	5.1
	3195	silt and clay	110 (34)	2	68	30	44	23	18	5	0.17	1.73	1.17	0.025	47	6.1

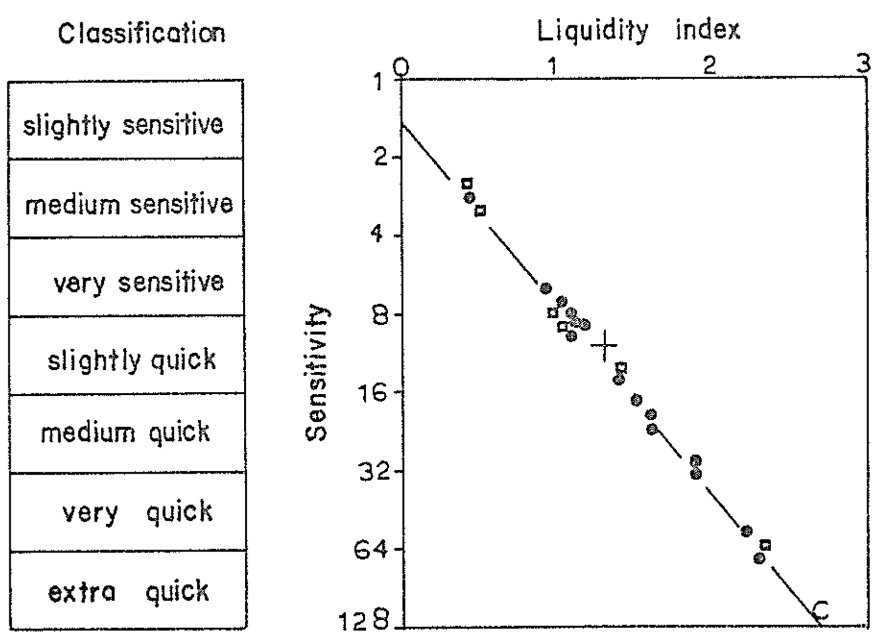
Table 4-5 Strength and index properties of Moisie River clays
QDNR dossier 5417-22, 1974

Sensitivity values, defined as the ratio of undisturbed to remoulded strength, from borehole shear vane data range from 1 to 52. The remoulded strengths were about 0.02 kg/cm^2. When the author's own tests were made, remoulded strengths were too low to be precisely measured by the Geonor and Pilcon field vane equipment, but at the site of the Sept-Iles landslides the sheared material flowed out in a slurry, indicating extremely low remoulded strength. Bjerrum (1954), and Eden and Kubota (1961) have shown that there is a direct relationship between the liquidity index and sensitivity. The results of the author's data were plotted on Bjerrum's chart (Figure 4-9), since Bjerrum derived his linear equation from field, rather than laboratory data. On Bjerrum's graph the sensitivity of North Shore clays plot from 3 to 64, and average about 12. According to this scale, the clays vary from "medium sensitive" to "very quick".

Strength loss upon disturbance has been discussed in the preceding subsections. In summary, a number of factors, in combination, could be responsible for the high sensitivity ratings in this area.

1. The soils have a flocculated structure which contributes to structural strength but contains large amounts of pore water.
2. Due to leaching, the pore water is not bound to soil particles and therefore disturbance causes release of water and soil in a slurry.
3. Pore water chemistry affects the distance over which repulsive forces on clay particles can act.
4. Upon disturbance, there may be a complete loss of strength because a large proportion of the clay size particles are rock flour, which have brittle, short-range bonds.
5. Certain pore water chemical constituents encourage weathering of chlorite and amphibole, and subsequently cause release and precipation of iron, potassium, and aluminum cement at interparticle contacts. According

Figure 4-9 Sensitivity values for North Shore clay
(after Bjerrum, 1954)



• massive clay, ▫ banded clay, C Toulnustouc clay,
+ average of 700 QNS & L RR samples

to this explanation, the high sensitivity is created by high initial shear strengths rather than by low remoulded strength.

Landslides

The morphology of exposed offshore marine deposits

Landslides are characteristic features of exposed or near surface deposits of the offshore sediments. The slides are distributed along river and beach bluffs, both presently active or abandoned, and along road and rail cuttings. Slides are generally clustered, as is the case in the St. Lawrence Lowlands (Chagnon, 1970). Active slides occur in areas where remnants of former slides can also be seen.

The location and geometric characteristics of individual landslide sites will be presented later (see LANDSLIDE INVENTORY). Some general characteristics are mentioned here.

On the air photos slides appear as circular arc sections. Within these are crescents of slumped blocks. Bottleneck slides, common in the lowlands (Gadd, 1971), are rare in this area. The slides have cross sections similar to the theoretical section described by Karrow (1972; Figure 4). Slumped slices are located towards the back of the slide. Beyond these are zones of hummocky ground composed of isolated blocks of intact clay in a sea of amorphous flow debris. Beyond the bowl of active slides are aprons of material that flowed out in a slurry. These aprons are absent on inactive slides, suggesting their removal at times of higher sea level by waves, or by river currents. Individual bowls are separated by spurs of stable material.

The information in the preceding sections indicates that at least some of the marine sediments in the area are in a potentially unstable state.

Those areas in which landslides have actually occurred are areas where stream and wave erosion have caused oversteepening of exposed faces of clay, or where slopes have been oversteepened by human activity. During the field season, flowslides occurred during and immediately after heavy rainfalls. Those observed at Sept-Iles in 1972 were confined to areas in which the natural soil drainage was restricted by the geometry of the deposits, and it was probably the increase in pore pressures and static load that triggered the failure. Small slides also occurred after rainfalls where "case-hardened" slopes were very steep (about 60°). In these areas it was found that rewetting of the desiccated face produced loss of strength; the slope was then too high and too steep to resist movement.

Some comments on slope stability studies

The engineering reports referred to in this thesis, and some of the published studies (e.g. Woods, Pryer and Eden, 1959) have used $\phi = o$ analyses to predict slope stability in the massive and banded sediments. It can be argued that this type of analysis is valid on empirical grounds because people working on similar Leda clays have found that the strength of those clays is attributable to cohesion due to interparticle bonds and forces (Crawford, 1963). The role of cohesion (vs. friction) was also stressed by Quigley (1968), who concluded that much of the strength in the Toulnustouc clays was attributable to strong bonding produced by aluminum and iron hydroxide precipitates. The additional theoretical assumptions associated with $\phi = o$ analyses as discussed by Lambe and Whitman (1969 chapter 31) are also met in the field situations. At failure the slopes have been saturated and the slides themselves occur under "undrained" conditions because observed failures occurred too rapidly to permit drainage.

Other indications, however, suggest that the role of friction should not be ignored. Firstly, the prevalence of rock flour in the sediment implies that a large component of the strength should be frictional, and that unless particles are cemented, cohesion should be relatively low.

Secondly, slickensides are present on the sidewalls and backwalls of slide scars at Sept-Iles (cf Figure 7-11). These striations are inclined to about 33^{o} from horizontal along the sidewalls. They suggest that friction was actively operating to resist movement at the time of failure.

Lastly, Conlon's laboratory tests show that both cohesion and friction are important in calculating stability conditions of slopes in this region. In an effective stress analysis of the Toulnustouc clays, he showed that the effective angle of internal friction was 36^{o} at failure.

4.3 Nearshore and Estuarine Sand

Distribution and material

A coarsening-upward layer of stratified sand overlies the deepwater clays. The basal contact with offshore silty clay, as it is displayed along the banks of the Moisie River, is undulatory and erosional, but elsewhere this sandy unit grades into banded offshore clay. The upper part of the unit, as it is exposed near the Sept-Iles airport, grades into the overlying beach sands. The material consists of the fine sand fraction of outwash that was transported and deposited into fiords and estuaries during the marine submergence.

The thickest accumulations are deltaic wedges, situated where sediment-laden currents emptied into the extended St. Lawrence estuary. The three-dimensional geometry of these deposits is difficult to determine, although fan-like planimetric shapes are visible on air photographs. The limited number of borehole reports show that changes in both internal structure and total thickness can occur abruptly. Beneath the Moisie River at the Highway 138 (Route 15) bridge site, for example, borings are 120 feet (37 m) apart (QDNR, 1974); although all logs record fine sand, the types of bedding structures differ greatly from hole to hole. These logs indicate that channel infillings of sand extend to at least 43 m BSL (below the present river bottom), but on the nearby east bank, silty clays begin at 73 m ASL.

Deposits included in this unit are exposed along the lower Moisie River and its tributary gullies and in pits south of the Sept-Iles airport; along the Ste - Marguerite River and adjacent coast, the sand pits north of the Ste-Marguerite Dam, and in railway cuts near Pointe Noire; in the Rivière aux Rochers west of Lac Walker; along Rivière Pentecôte, whose banks expose more than 75 metres of estuarine sand; and in the Petite Rivière de la Trinité, Grande Trinité, Franquelin and Godbout Valleys below the marine limit. The deposits are also reported in borehole logs from Moisie River, Sept-Iles townsite and airport, Lac Hall bridge, Clarke City and Lac Walker bridge..

Texturally the sands are fine-grained (average size = 2.97 ϕ = 0.13 mm for 22 samples) and moderately sorted (σ = 0.71). In the lower parts of sections the silt content increases and the material becomes slightly cohesive.

The sands have loose to medium relative densities (tests at six field sites and three borehole areas) (Table 4-6). The density increases slightly with increasing depth. Dry unit weight averages 1.6 g/cc and bulk densities range from 1.4 to 2.1 g/cc. Water contents vary from 3% to 24%; samples with highest moisture values are the lowermost silty sands. The pore water has a pH near seven. Pumping tests at Sept-Iles yielded permeabilities of $4X10^{-3}$ to $12X10^{-3}$ cm/sec (moderately permeable) which is two to six times less than the values obtained for the overlying littoral sands (Iron Ore Company report 8717, 1970).

The sands have mineralogies characteristic of the local igneous source rocks. The mica content, primarily biotite and phlogopite, is particularly high in the medium and fine sand fraction. Quartz grains are very angular; feldspar and ferromagnesian silicates have subangular to subrounded edges. The macroscopic surface texture of the grains resembles that of the tills; there has been little modification caused by water transport and depositional processes.

Sedimentary structures

There are three types of sedimentary sub-units associated with the nearshore environment. The lowermost sub-unit comprises subhorizontal planar strata which are thinner and more nearly horizontal than those in the unit above. They consist of fine grey micaceous sand separated by laminae of steel grey clay. In the lower parts of exposures between the first and second falls at Rivière Pentecôte the clay strata become thicker than the sand strata, and the unit grades into the banded prodelta

Table 4-6 Density and penetration resistance in nearshore and littoral sand

Sample Reference	bulk density (g/cc) wet	dry	w%	pH	penetration resistance (kg/cm^2) cone penetr.	pocket penetr.	density description	% silt-clay
Sept-Iles Airport								
74-1 (lowest)	2.05	1.70	21	7	4.05	1.43	dense	20
74-2 (middle)	1.91	1.74	14	7				0
74-8 (middle, bedded)	1.81	1.66	9	6.5	1.81	0.84	med.	1
74-9 (beach)	1.68	1.62	4	5.5	2.1	0.72	med.	0
74-9 (indurated)					16	>5	dense	0
Iron Ore Co., 1970	1.73	1.66	4	and Ø = 33°. Loose at surface, compaction increasing with depth				
Moisie River area								
74-12 Mile 12 (sand pit)	1.77	1.68	4	6.0	1.44	0.82	med.	0
74-12 Mile 12 (indurated)					90	>5	dense	
74-6 (gully sand)	1.36	1.32	3	7				1
74-29 (gully resedimented)	1.68	1.64	3	7				0
QDNR 1972, @ 20'	N = 5-36		24				loose-med.	1
40'	N = 10-30		24				med.	10
60'	N = 10-30		24				med.	80
Ste. Marguerite area								
74-53 (Route 15)	1.82	1.62	13	7				2
74-52 (Arnaud)	1.76	1.67	5.3	7				3
Hall River	N = 1-9						loose	
Walker Lake	N = 10-30						med-dense	

silty clays described previously (Figure 4-10).

The intermediate and most extensive unit is the delta sets (Figure 4-11). The sets consist of tabular strata one to two metres thick, dipping seaward at angles up to 15°. Except for one lobate form which may be a slump-flow relict, there are no large-scale structures within these beds. Close examination reveals internal asymmetric ripple-drift forms, and thin concentrations of heavy minerals; cross laminae and planar clay laminae (about 1 mm thick) appear in the lower parts. These structures are similar to deltaic deposits observed by Chagnon along the Gouffe River (1969, plate 2B).

The third and uppermost unit, as characterized by exposures in the Moisie gully, has structures associated with sedimentation under the influence of fluctuating currents of moderately high energy (Jopling, 1963). Structures include festoon and tangential cross strata, and contorted beds of silt with discontinuous lenses of silty clay.

Depositional environment

1. Passega's work on textural/transport relationships along the Mississippi River and Delta (Passega, 1964) provides a basis from which fluvial sedimentation processes can be related to grain size data. Passega's graph (Figure 4-12) shows in a general way, the different transport mechanisms operative in the overall coarsening upwards sequence. The horizontally bedded silty sediments which underlie the delta sets comprise zone VII of Passega's diagram. There were carried in graded suspensions, without rolling, and probably represent bottom sets. The sands which comprise what has been interpreted as delta foresets were probably transported by tractive currents, primarily as graded suspensions near the bottom (zone V). Some particles were also rolled down the foresets, as evidenced by ripple drift structures and grain size data, but particle shape suggests that

Figure 4-10 Transition zone between banded clays and estuarine sand, Rivière Pentecôte.

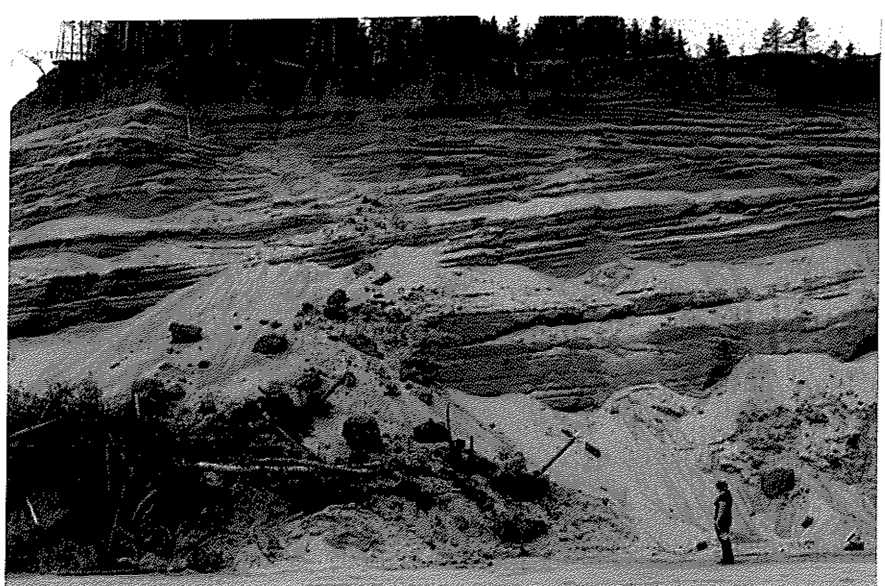


Figure 4-11 Estuarine delta foresets, (map unit 5b), grading upward to beach sand (top metre). Photo taken at pits south of Sept-Iles airport.

Figure 4-12 Tractive tranport curve (Passega,1964)

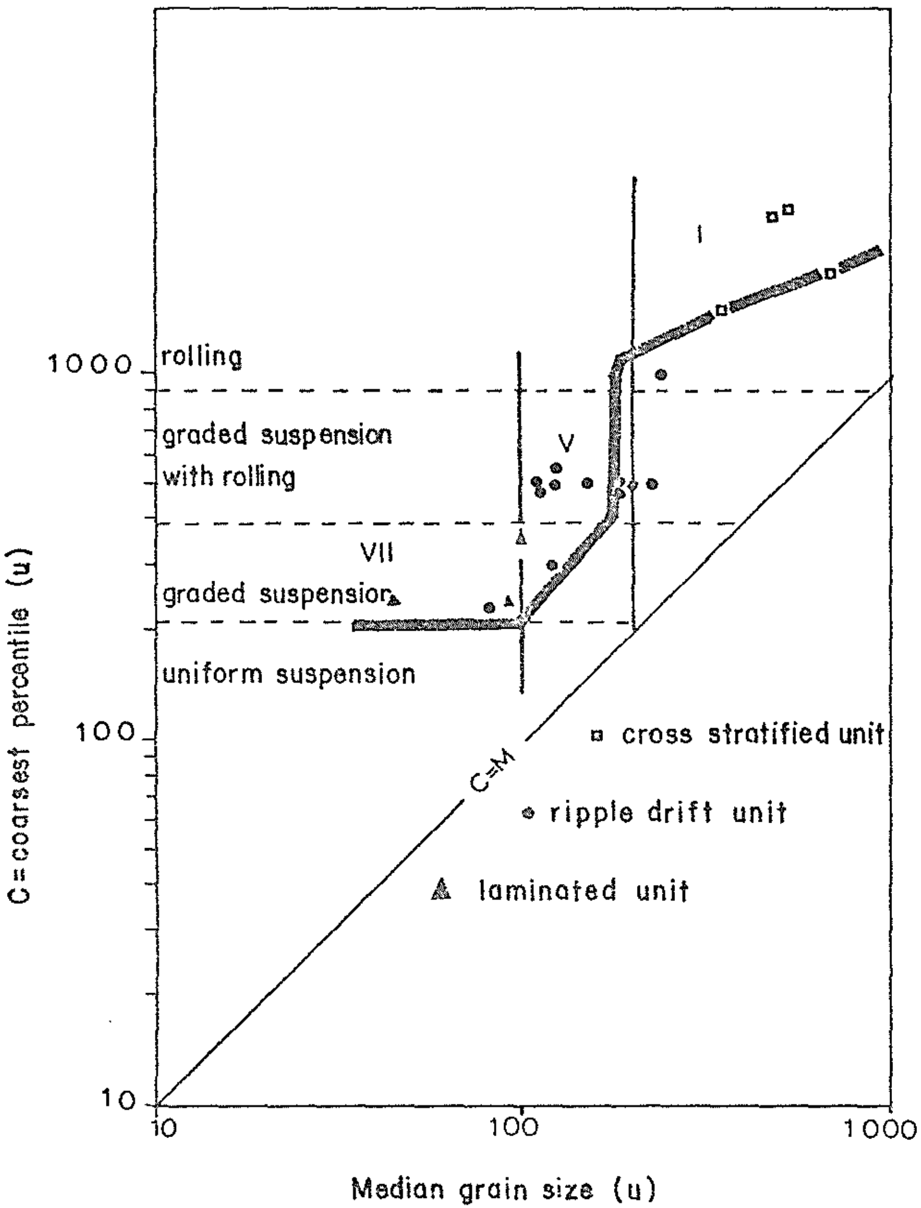
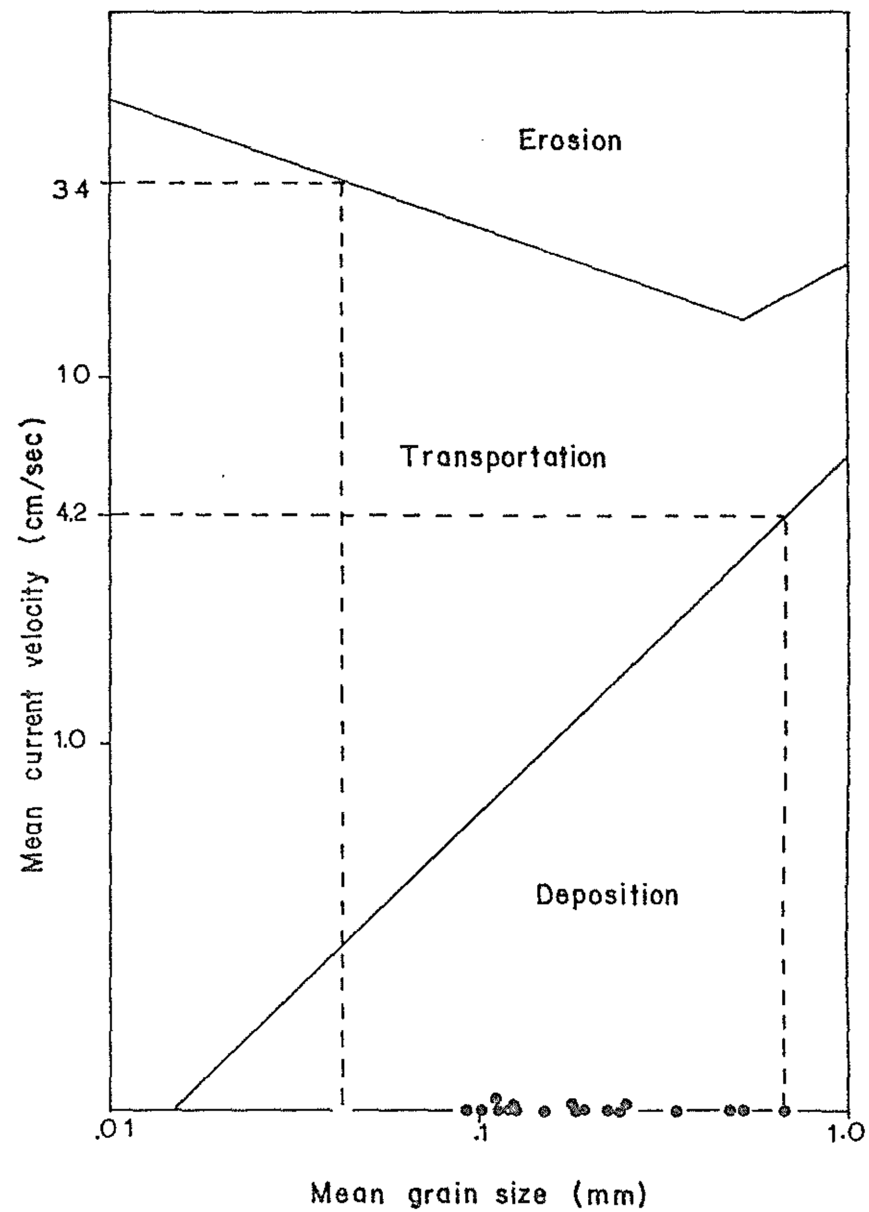


Figure 4-13 Hjulstrom's diagram (1939)



rolling was not extensive enough to abrade the surfaces of the grains. The uppermost structural unit, characterized by coarse material and crossbedded structures was reworked and resedimented after rolling (zone I).

2. Hjulstrøm (1939) related critical transport and deposition velocities to particle size. According to his graphs, deposition of the nearshore sediments would occur when velocities were less than 4.2 cm/sec (Figure 4-13). (Deposition occurs at about 130 cm/sec for normal river currents and at about 20 cm/sec for longshore currents.) The weakness of the current at deposition suggests that the water was fairly deep, and according to Passega's chart (1964, p. 837) the water depth was probably between 30 and 45 m.

3. Given that the deltaic sediments were formed in more than 30 m of water, and that the present elevation of the beds is up to 75 m ASL, much of the deposition must have occurred within the first thousand years after deglaciation, when sea level was at or near its maximum of 130 m ASL.

4. Sedimentation was rapid. This is implied firstly by the entrapment of fines and lack of graded bedding in the deposits, despite graded suspension modes of transport. Secondly, in some places sedimentation was fast enough to prevent sand grains from arriving at stable positions or packing arrangements as they avalanched down the foreset slopes. As a result the sands have high void ratios, loose to medium densities and metastable structure (as defined by Terzaghi and Peck, 1967). In addition, the heads of the main deltas are situated at the edge of an escarpment, where fiord currents once spilled out from their confined channels into the Goldthwait Sea. For any given discharge, the sudden lateral expansion into a relatively still body of water would result in a rapid decrease in velocity and therefore deposition.

Detrital wood from foreset beds at 27 m at Moisie has been dated at 6380 ± 150 BP (GSC-1482; locality 10 on Fig. 4-22). This date in conjunction with a shell date of 7060 ± 190 (GSC-1552), at the base of the same section, would suggest that the minimum rate of sediment accumulation was about three centimetres per year; however, this value may be grossly inaccurate, because coeval wood and shell samples from other areas have yielded age differences up to 1000 years (the shells being the older).

5. Hjulstrøm has shown that sediments with textures of those in the deltas can be eroded when fluid velocities exceed 34 cm/sec, which is much less than the current velocity of moderate-sized rivers. The upper parts of former nearshore deposits were therefore eroded or restructured when the water level shallowed sufficiently to bring them into the zone of wave and current activity.

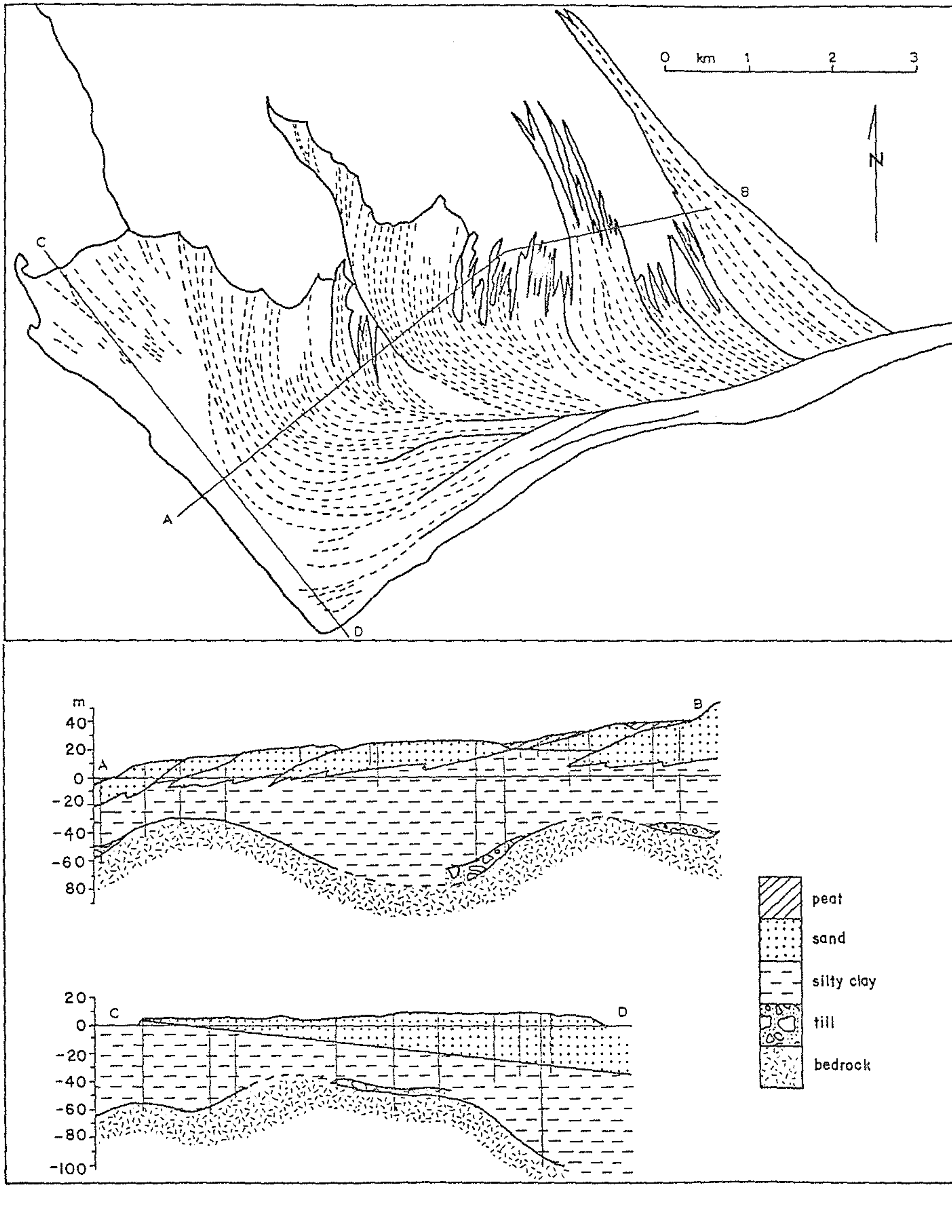
4.4 Littoral Sediments

Distribution and characteristics

Most of the coast plain between the marine limit and present sea level is covered by a layer of beach sand deposited during the marine regression. The material comprising these littoral deposits originates from the dissection and reworking of former delta surfaces. The largest accumulations of beach sand are associated with Rivières Moisie, Ste-Marguerite, Pentecôte and Rochers. Smaller sand plains are associated with Rivières Godbout, Trinité and Franquelin. The reworked delta-top topography consists of almost flat terraces separated by small erosional scarps. Microrelief is produced by sets of rounded beach ridges and shallow lagoonal troughs which have become filled with peaty material.

The area north of Sept-Iles has two morphological forms not found in the rest of the area. The first is a flight of prograding ridges extending from the 60-metre terrace to the marine limit at 128 metres, and situated between the road to Lac Daigle and Rivière Moisie. The second feature is a complex recurved spit, on which the Sept-Iles townsite is located. Airphotos and borehole records show that it was built in six segments by currents transporting material from east to west (Figure 4-14).

Figure 4-14 Plan and cross sections of the recurved spit at Sept-Iles



area below marine limit. Beach deposits have a thickness of 2 to 5 metres, although they have been mentioned in drilling reports to depths of 20 metres near the village of Maliotenam. Borehole records and open exposures show that near the Sept-Iles airport the beach material grades downward into finer, grey, nearshore sands. From very limited borehole data, this is the case in the Ste. Marguerite area as well. Elsewhere, beach sands lie unconformably over silts and clays, or as a veneer over bedrock, as in the Pte Jambon area or the zone between Pentecôte and Baie-Trinité. The beach sands grade laterally into fluvial deposits in the Rivière aux Rochers area and along the right bank of the Moisie River.

Structure and texture

Characteristic beach structures are well preserved. On flat areas bedding consists of planar strata 5-10 cm thick; the thickness of any one stratum is uniform over its exposed length. Each stratum is composed of planar laminae which are produced by compositional differences; light brown laminae are medium to coarse-textured and are composed of a mixture of light and heavy minerals, whereas darker laminae are composed of smaller, heavier grains alone (Figure 4-15). The strata are sub-horizontal, and dip gently seaward at five degrees. They were probably developed in a foreshore environment, with successive strata being deposited parallel to the beach surface. The low dips and constant dip direction are a characteristic of foreshore deposits emphasized by McKee (1957).

In areas where beach ridges prevail, more diverse stratification was observed, especially below ridge crests (Figure 4-16). Cross laminations are present in lenses or wedges which truncate or are truncated by the planar laminations. The angles and directions of the cross laminae and some of the planar laminae below the crests are variable. These types of

Figure 4-15 Subhorizontally bedded beach sand (map unit 6a) at the marine limit south of Lac Daigle.

Figure 4-16 Cross stratification below a beach ridge crest of QNS&L milepost 3.

structures are probably associated with a backshore or high-foreshore environment, where erosion and redeposition by wind, storm waves and runnel scour produce reverse stratification. The occurrence of landward dips in the backshore environment has been previously documented by Klein (1967).

Near the marine limit the sands are coarse, dirty, poorly sorted, and generally similar to their parent material, till. Below this level, where sands have been subject to coastal processes for longer periods, the average grain size tends to decrease, while sorting improves (Dredge, 1971, Figure 11). The sands generally are medium to coarse grained. For 26 samples the average size is 0.47 ϕ (0.71 mm), about average for beach sands (Folk, 1962), but size varies from one stratum to the next. They are also moderately well sorted (σ = 0.67 ϕ units), and very clean. The sands are often slightly positively skewed, which is contradictory to the results of Freidman (1961) and Mason and Folk (1958), who used a negative skewness to distinguish between beach and dune sands. The tail in the fines can be attributed to two factors: (1) With a constantly falling sea level there may not have been sufficient time for complete winnowing of the fines by wave activity and (2) the accumulation of heavy minerals, especially magnetite in the fine sand fraction here seems to be generally greater than in other regions. Iron minerals (magnetite-ilmenite and hematite) make up to 17% of the sand by weight at Moisie.

The principal mineralogical components of most of the strata are quartz and feldspar, but some amphibole/pyroxene is present and there are small quantities of biotite. The quartz is fairly angular and only slightly abraded, but the edges of feldspars and most heavy minerals are rounded. Other strata are composed primarily of heavy minerals, chiefly magnetite and garnet, and these are interpreted as storm accumulations.

On the present beach, concentrates of heavy minerals up to four centimetres thick accumulate during storms. Assays of storm deposits at Moisie show them to have up to 65% iron content.

The sand has a loose to medium relative density (penetration resistance varies from 0.7-2.0 kg/cm^2) below the hardpan which constitutes the Bf horizon of the soil. The hardpan could not be penetrated by manual probing vertically, and was extremely difficult to penetrate horizontally. The sands are neutral to slightly acid (pH = $5\frac{1}{2}$ to 7). Despite the hardpan, the soils are well drained and the soil water contents in the upper five metres are about four per cent of the dry weight. The more extensive sand plains are large aquifers. Pumping tests at Sept-Iles yield hydraulic conductivity values of 2.4×10^{-2} cm/sec for beach-type sand but falling head permeameter tests of the same material produce values of 1.6×10^{-3} cm/sec. Despite the substantial range, the tests both indicate that permeability is fairly high, and that it is about four time greater than the permeability of the underlying finer estuarine sands.

Tidal flats and boulder ramparts

Along most of the present coast the intertidal zone is sandy, but besides the beach deposits described above, clay flats and boulder ramparts occur there as well.

The inner Baie des Sept-Iles is a large salt marsh and tidal flat consisting of soft, very sticky, greasy, grey clay (Figure 4-17). The clay has a low plasticity (Ip = 7) despite its greasy feel and is classed as OL-CL in the Casagrande system. This clay differs from the offshore deposits in that augering reveals discontinuous, black horizontal organic bands and vertical worm burrow casts. Small ridges of contorted sediment

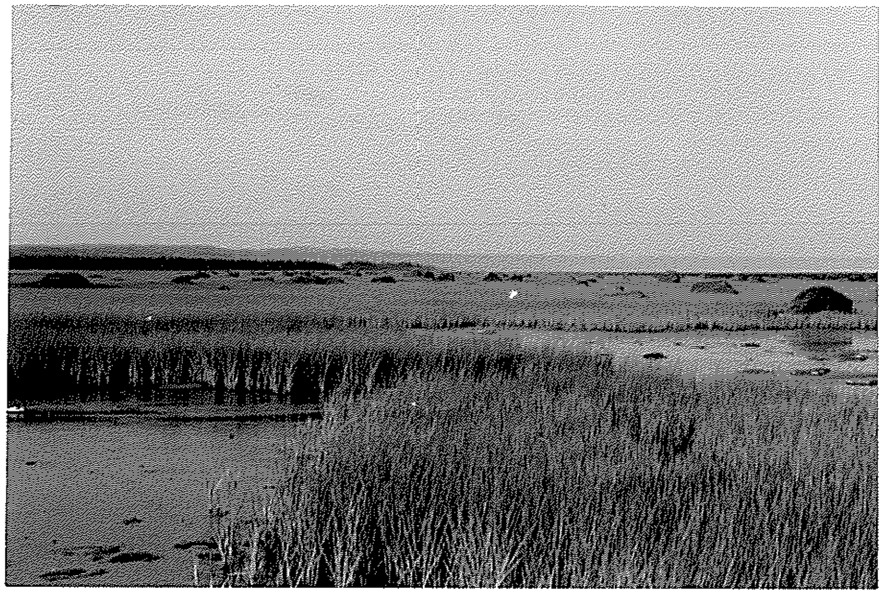


Figure 4-17 Tidal flat within the Baie des Sept-Iles showing typical components: grey clay, ice rafted boulders, and salt marsh vegetation. Map unit 6d.

Figure 4-18 Relict tidal flat clay and ice rafted boulder, overlying littoral sand. Photo was taken about one kilometer east of the mouth of Rivière des Rapides.

lie both landward and seaward of large boulders. These ridges are produced by the bulldozing action of boulders when they are pulled and shoved by ice during the winter and spring. The clay flat is also characterized by its cobble pavement. Cobbles embedded in the clays are sheared or abraded off at about low tide level, probably by the action of gritty grounded ice.

Relict tidal flat deposits are found immediately north of the Baie des Sept-Iles up to an elevation of 40 metres. Over much of this area the intertidal deposits overlie former offshore sediments, but between Lac des Rapides turnoff and Rivière des Rapides another thin tidal clay deposit overlies beach sand on the 30 metre terrace (Figure 4-18).

One of the most distinctive features of the present coastal zone is the boulder rampart. This has been extensively documented on the Gaspé shore by Dionne (1974). The boulders occur in concentrations above winter low tide line, the place at which rafted ice becomes grounded. The major accumulations in the field area occur in the Baie des Sept-Iles tidal flat, from Pte aux Anglais to Ilets Caribou, and at the mouths of the Godbout, Franquelin and Trinité Rivers. The boulders are irregularly shaped, and striated, but edges are round. The largest measured boulder was eight metres in diameter.

The origin of the boulder ramparts is not always clear. In river mouth sites the boulders have predominantly local lithologies. In the Baie des Sept-Iles about 25% are definitely local (as determined by their high magnetite content) but up to 60% were gabbroic, the general lithology of the adjacent area. Gneissic types within the Baie have probably been transported by ice-rafting from areas east of the Moisie River. The boulders here could have been prized from rockwalls and rafted by both river and marine ice, but some other ramparts (e.g. at Ilets-Caribou) may represent the wave-worked remnants of moraines.

Figure 4-19 Boulder barriers along the present shore at Ilets-Caribou (upper) and Pointe-aux-Anglais (lower). Map unit 6c.

Figure 4-20 Boulder beach derived from a relict boulder barrier. Wave action has sapped a shore bluff which was capped by a boulder barrier and reconcentrated the boulders at the base of the bluff, Ilets-Caribou.

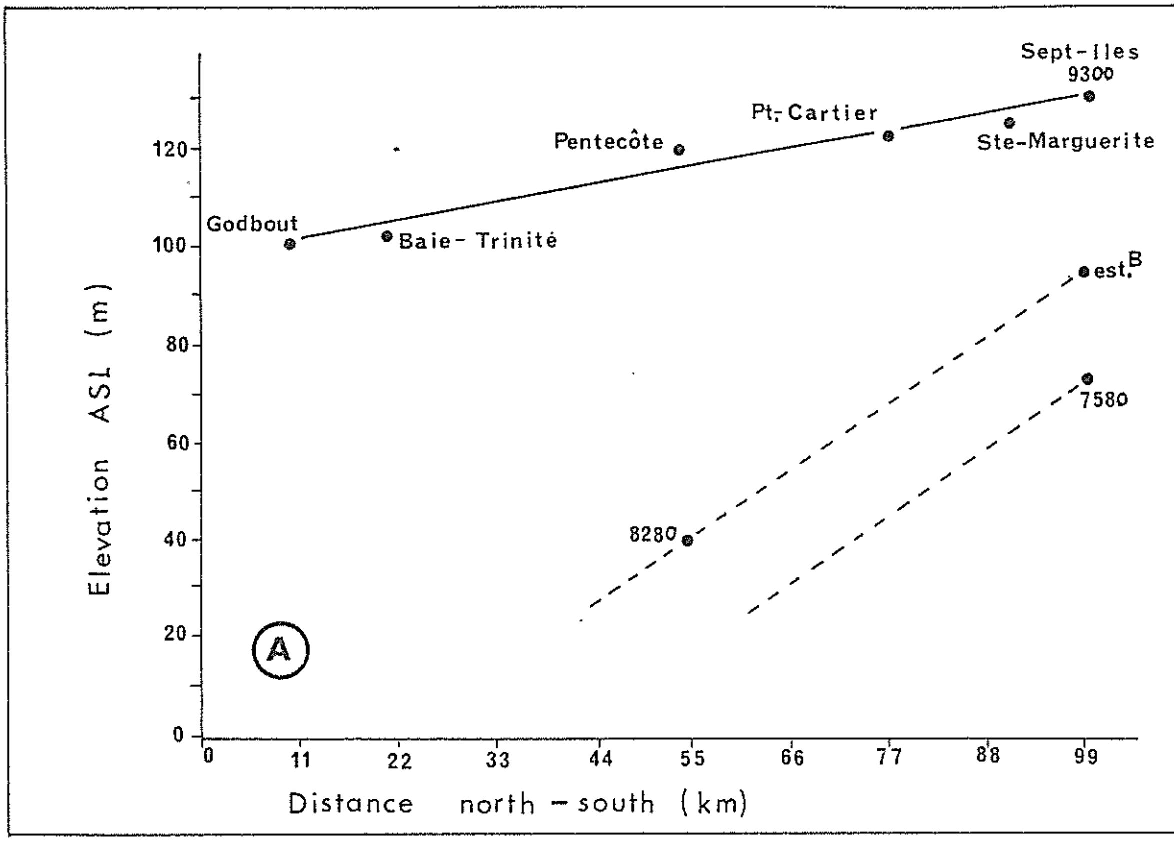
The rampart at Ilets Caribou differs from those in other areas because the boulders are almost spheroidal and extremely well rounded. They originate within, and are reconcentrated at the foot of a wave-eroded bluff of boulder gravel (Figure 4-20). The accumulation appears to be at least a second generation rampart resulting from the erosion of former ramparts on the nearby 45-metre sand terrace.

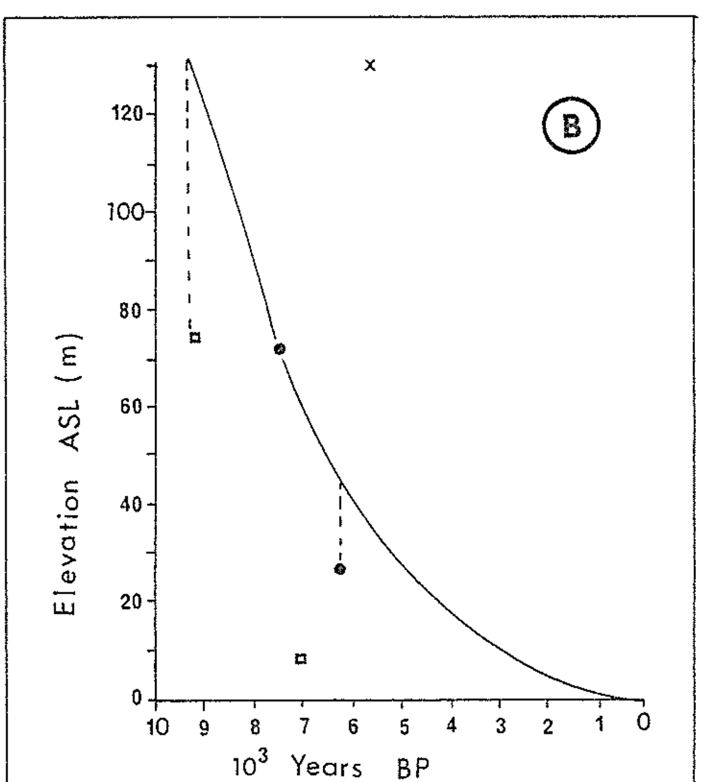
Marine limit determinations

Conditions during the marine regression were favourable for the development of beaches, and in some places the marine limit can be determined by the elevation of the highest beach deposits. Where access by road was possible, the marine limit was determined from closed altimeter traverses from geodetic control points. In most cases, the transition from well sorted sediment to till was fairly abrupt. Between Baie-Trinité and Pentecôte, and east of Port-Cartier, high level pocket beaches were located on air photos. The highest levels, as determined from topographic maps, were recorded as marine limit approximations. In the fiord valleys, the marine limit was taken to be the elevation below which kettle holes were no longer visible on the terraces. The altitude of the marine limit so determined consistently increased from south to north. The limit was found to be 100 m near Godbout, 103 m at Baie-Trinité, 120 m at Pentecôte, 123 m at Port-Cartier, 125 m at Ste - Marguerite and 128-130 m north of Sept-Iles (Figure 4-21).

On the delta surfaces, prominent terrace sequences have developed during the marine regression, but it was difficult to correlate absolute and relative terrace elevations from one delta to another. These difficulties are further discussed later.

Figure 4-21. Marine limit and emergence graphs





(A) Changing elevations of the marine limit from south to north across the field area (solid line). Also shown are possible slopes of synchronous waterplanes (dashed lines) based on two shallow-water dates and one extrapolated date.B

(B) Emergence data from Sept-Iles: • shallow water sites; ▫ deepwater sites; × pollen core date

4.5 Paleontology of Marine Sediments

Fossil fauna are present in sediments of the marine submergence, although few fossil localities were discovered, considering the extent of the field area. Many of the shells are thin-walled and fragile. Their fragility may result from the absence of natural carbonates in the marine environment of the North Shore.

A short list of mollusc species from the Moisie River area was published by Laverdière (1952). The accompanying tables (Tables 4-7 and 4-8) list species and site characteristics for localities discovered during the present field work. Elevations (Table 4-8) were determined from topographic maps, with the additional aid of a Paulin altimeter. The 43 molluscan species listed include 14 genera and 21 species not recorded in references to Champlain Sea faunas (Wagner 1967, 1970) although there are only 15 species that have not been previously reported in other lists (Wagner, 1968).

The highest site (number 1) is at 100 m ASL, about 10 metres below the local marine limit in the Franquelin area. Very little information was derived from this locality since only a few widely scattered shell fragments were found.

The next highest locality (number 2) is situated above the south portal of the QNS&L tunnel near the Moisie River at elevation 77 m. Articulated valves suggest that the shells are in place, and the species indicate cold water conditions. Since the shells lie within deep water banded clays they do not represent a sea level stand at 77 metres. The date of 9140 ± 200 (GSC -1337; Lowdon et al., 1971) which was obtained from these shells can be regarded as a minimum date for the marine limit, which is at 130 metres in the Sept-Iles area. This date is similar to that obtained from shells

Table 4-7 Marine fossil assemblages

Species / Locality	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Thracia septentrionalis Jeffreys				●														
Nucula tenuis (Montagu)						●												
Yoldia myalis (Couthouy)			●			●												●
Nuculana buccata (Steenstrup)									●									
Nuculana minuta (Fabricius)									●									
Nuculana pernula (Müller)						●												
Mytilus edulis Linné		●	A					●	●		●	A						
Clinocardium ciliatum (Fabricius)			A			●		●		●	●			●		●	●	●
Serripes groenlandicus (Bruguière)		●	A				●	●	●	●	●			●	●			●
Chlamys islandica (Müller)		●						●										
Cyclocardia borealis (Conrad)											●							
Astarte undata Gould								●										
Astarte montagui striata (Leach)											●							
Arctica islandica (Linné)								F					A					
Mesodesma arctatum Conrad					●													
Mesodesma deaurata Turton				A	●													
Spisula sp					●					●								
?Mysella planulata (Stimpson)				●														
Macoma balthica (Linné)			●		●	●		●				●		●				
Macoma calcarea (Gmelin)	F	●	●		F	●	A	●	●	●	A	●		●			A	●
Ensis directus (Conrad)													●					
Hiatella arctica (Linné)		●	●					●			●	A						
Cyrtodaria siliqua Spengler		●																
Panomya arctica (Lamarck)													●					
Zirphaea crispata (Linné)								●										
Mercenaria mercenaria (Linné)												●						
Mya arenaria Linné						●		●		F								
Mya pseudoarenaria Schlesch				●			●	●	●		●	F	●	●		●	A	
Mya truncata Linné		●	●		●			●		●		●	●		●			
Mya truncata uddevallensis Forbes												●						
Mya sp.											●							
?Margarites sp.				●														
Littorina saxatilus (Olivi)												●						
Natica clausa Broderip & Sowerby						●		●										
Lunatia pallida (Broderip & Sowerby)			●						●									
Boreotrophon clathratus Linné?									●									
Boreotrophon truncatus (Strøm)?												●						
?Amauropsis sp.			●															
Buccinum hydrophanum Hancock								●										
Buccinum undatum Linné									●	●								●
Buccinum tenue Gray												●					●	
Buccinum polare Gray																	●	
Buccinum sp.			●			●												
Colus stimpsoni (Mörch)						●												
Neptunea despecta tornata (Gould)																	●	
Balanus balanus (Linné)		●					●				●	A						
Balanus crenatus Bruguière												●						
Balanus homeri (Ascanius)									●									
Hemithiris psittacea (Gmelin)								●										
Strongylocentrotus droebachiensis (Müller)											F							
Islandiella teretis (Tappan)								●										
Globobulimina auriculata gullmarensis Höglund								●										
Buccella frigida (Cushman)				●														
Elphidium bartletti Cushman				●				●										
Elphidium excavatum clavatum Cushman				●														
Elphidiella sp.								●										
Protelphidium orbiculare (Brady)				●				●										
Nonion sp.								●										
Nonionellina labradorica (Dawson)								●										

A abundant

● present

F fragments

Shells at Site 2 identified by V. Condé, McGill University. Forams identified by F.E. Cole, Atlantic Geoscience Centre. All others identified by F.J.E. Wagner, Atlantic Geoscience Centre.

Table 4-8 Fossil reference data

Number	Field reference	Locality	Lat./Long.	Elevation	Substrata	Radiocarbon date/Reference	
1	74-92	Franquelin/Lac à la Ligne	49°18'N/67°51'W	100 m	grey sandy silt		
2	69-1	Riv.Moisie at Mile 12	50°18'N/66°12'W	77 m	grey silty clay	9140 ± 200	GSC-1337
3	72-50	Riv.des Rapides	50°17'N/66°26'W	75 m	fine sand	7580 ± 70	GSC-1809
4	72-26	Riv.Pentecôte	49°45'N/67°10'W	45 m	fine sand	8280 ± 80	GSC-1856
5	72-27	Riv.Pentecôte at ramp	49°45'N/67°10'W	40 m	grey silt		
6	72-56	Riv.des Rapides/power line	50°17'N/66°26'W	40 m	grey silt		
7	72-41	Petite Riv. Trinité	49°31'N/67°14'W	30 m	grey clay		
8	72-9	Baie St.Nicholas dragline	49°17'N/67°57'W	30 m	grey clay		
9	74-98	Baie St.Nicholas (upper)	49°17'N/67°57'W	30 m	grey silt		
10	BGT	Riv.Moisie Gully	50°16'N/66°02'W	27 m	fine sand	6380 ± 150	GSC-1482
11	74-88	Baie St.Nicholas (lower)	49°19'N/67°48'W	15 m	grey silty clay		
12	72-12	Riv.Mistassini	49°17'N/67°57'W	12 m	grey silt		
13	72-49	Sept-Iles townsite	50°14'N/66°24'W	9 m	sand		
14	BGT/74-7	Riv.Moisie Gully	50°16'N/66°02'W	7 m	blue-grey clay	7060 ± 190	GSC-1552
15	70-X	Sept-Iles	50°14'N/66°24'W	7 m	silty clay		
16	72-11	Riv.St.Nicholas	49°19'N/67°48'W	7 m	sandy silt		
17	72-28	Sept-Iles Vieux Post	50°14'N/66°24'W	0-6 m	silty clay		
18	74-45	Sept-Iles Vieux Post	50°14'N/66°24'W	3 m	silty clay		

Shells found along present-day beaches at Ilets Caribou and Pointe des Monts   Salinity 30 $^{0}/_{00}$

Spisula solidissima, _Echinarachnias_ sp, _Lunatia heros_, _Ensis directus_, _Thais lapillus_, _Skenea planorbis_, _Littorina littorea_, _Siliqua costata_, _Thracia septentrionalis_, _Chlamys islandicus_, _Mya truncata_, _Mytilus edulis_, _Buccinum undatum_, Mesodesma arctatum, _Aporrhais occidentalis_, _Marguerites helicinus_, _Acmaea testudinalis_, _Mya arenaria_, _Spisula polynyma_, _Lunatia groenlandica_. Collected by L.A. Dredge

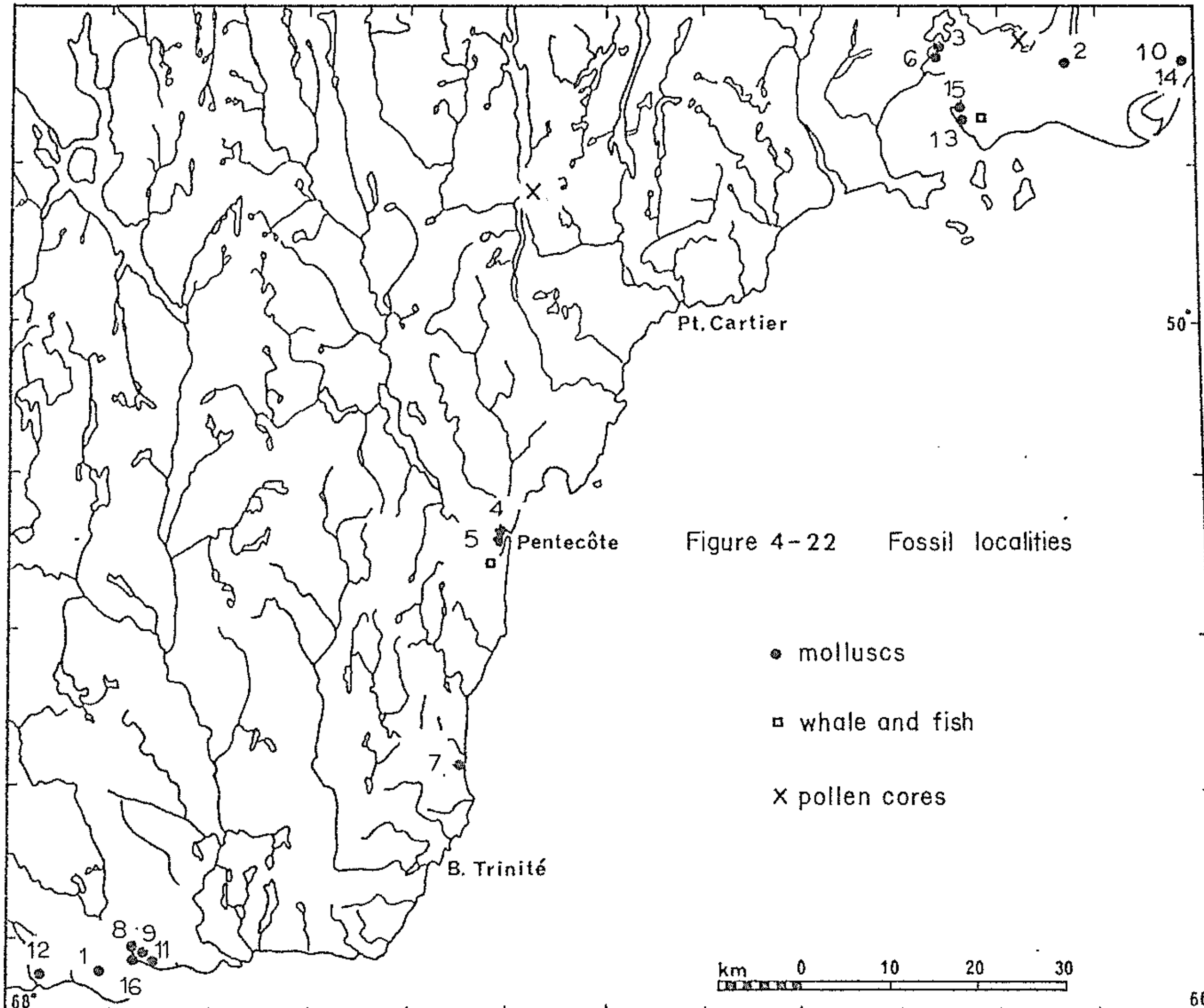


Figure 4-22 Fossil localities

at Manic II (9150 ± 150; Sauvé and LaSalle, 1968).

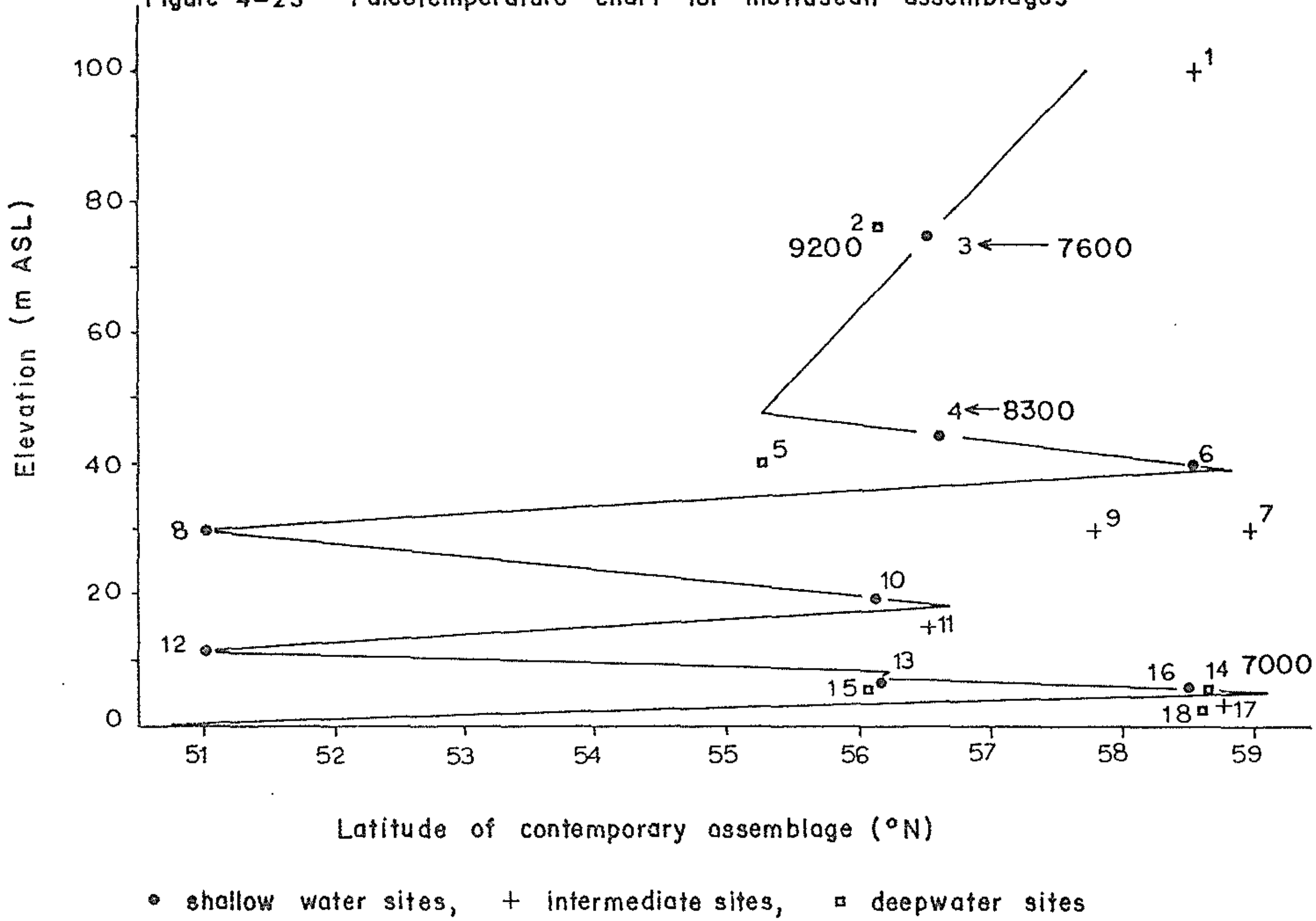
On the basis of textural and structural characteristics of the enclosing sediments, sites 3, 4, 10, 13 and 16 represent shallow water environments. At Sept-Iles (13) the valves are broken, but this condition may be a function of a high energy environment, rather than being indicative of transportation. Shells at Lac des Rapides (3) and Pentecôte (4) are articulated and in growth position. The dates obtained for them thus represent sea level stands at 75 m and 45 m respectively. The Rapides shells yielded a date of 7580 ± 70 BP (GSC - 1809; Lowdon and Blake, 1975) while those at lower levels at Pentecôte are dated 8280 ± 80 BP (GSC 1856). Since there is no obvious source of contamination in either sample, the dates suggest that uplift and deglaciation occurred significantly later in the Rapides area than at Pentecôte 60 km to the south.

Sites 8, 9, 11, 14 and 15 were found in massive clays and probably do not mark sea level stands. Shells at site 14, in the Moisie River gully, have been dated at 7060 ± 190 (GSC - 1552; Lowdon and Blake 1973). Based on the date at Rapides (site 3) (7580 BP) there was probably about 50 m of water above the sample when the molluscs were alive. Site 12 (Mistassini), while in massive clays, contains large quantities of *Mytilus edulis*. This site is interpreted as being a shallow marine environment, possibly a tidal flat.

Wagner has plotted fossil assemblages on graphs according to site elevation and the mean latitude at which the shells are presently found. These plots were used in West Coast studies to indicate thermal trends (Wagner, 1959).

The graph presented here (Figure 4-23) was drawn to intersect assemblages within very shallow water sediments. Other points on the diagram

Figure 4-23 Paleotemperature chart for molluscan assemblages



are indicative of the thermal environment of higher elevations (sea levels). Since the diagram is a composite of all sites in the area, the dates are very slightly out of sequence due to differential deglaciation and uplift.

The graph indicates that at the time of deglaciation the marine environment was somewhat cooler than at present. This cooling apparently continued into postglacial times, at least until about 8300 BP. The data indicate that there was a warming trend after that time, interrupted by several cooler periods. The earlier cool interval corresponds roughly to the time of the Cochrane readvance in other areas.

In addition to the mollusc and foraminifera species listed in the tables, three other faunal fossils were found. These were a crab claw from site 11 and the premaxillary (jawbone) from the genus Gadus (cod) from site 74-43 west of Pentecôte. A portion of a whale skeleton was found by E. Scherrer in 1972 in a foundation excavation within a raised terrace (18 m ASL) at Sept-Iles. The radiocarbon date of 1520 ± 70 (GSC - 1911; Lowdon and Blake, 1975) reported for this skeleton is anomalously low.

5 SURFICIAL MATERIALS PART C: POSTGLACIAL DEPOSITS

5.1 Aeolian Sand

Aeolian deposits are restricted to the extensive 50 to 60-metre sand terrace east of Sept-Iles and to the beach ridges which lie between 66 m and 90 m ASL near Baie Trinité. Both fields of dunes are presently stabilized by vegetation consisting of a lower stratum of *Vaccinium* sp. and *Ledum groenlandicum* and an upper stratum consisting primarily of an open pine and spruce woodland. Evidence of present day wind activity in these fields is restricted to a few small blow-outs on south-facing flanks of the Baie Trinité dunes and a layer of sand seven centimetres thick which overlies the bleached A soil horizon in the Sept-Iles area. The two dune fields have different geometrical characteristics (cf Figure 5-1) and histories, and are thus described separately below.

Baie Trinité dunes

This field consists of about 50 elongate compound ridges (Figure 5-2). The field is partially composed of individual V-shaped ridges, the smallest of which is 120 m in length. More commonly, these ridges coalesce and bifurcate, producing a complex ridge up to 1200 m long. The Vs are open towards the east-northeast and are symmetrical about a northeasterly axis. The highest parts of the dunes are at the apices of the Vs (southwest ends), which stand about 15 m above the surrounding sand plain. The foreslope of the apex stands at about eight degrees, while the slope along the axes of the limbs is two degrees.

The composition of the dunes is very similar to nearby beach sand. Both consist of yellow-brown medium to coarse sand in a unimodal distribution.

Figure 5-1 Dune patterns

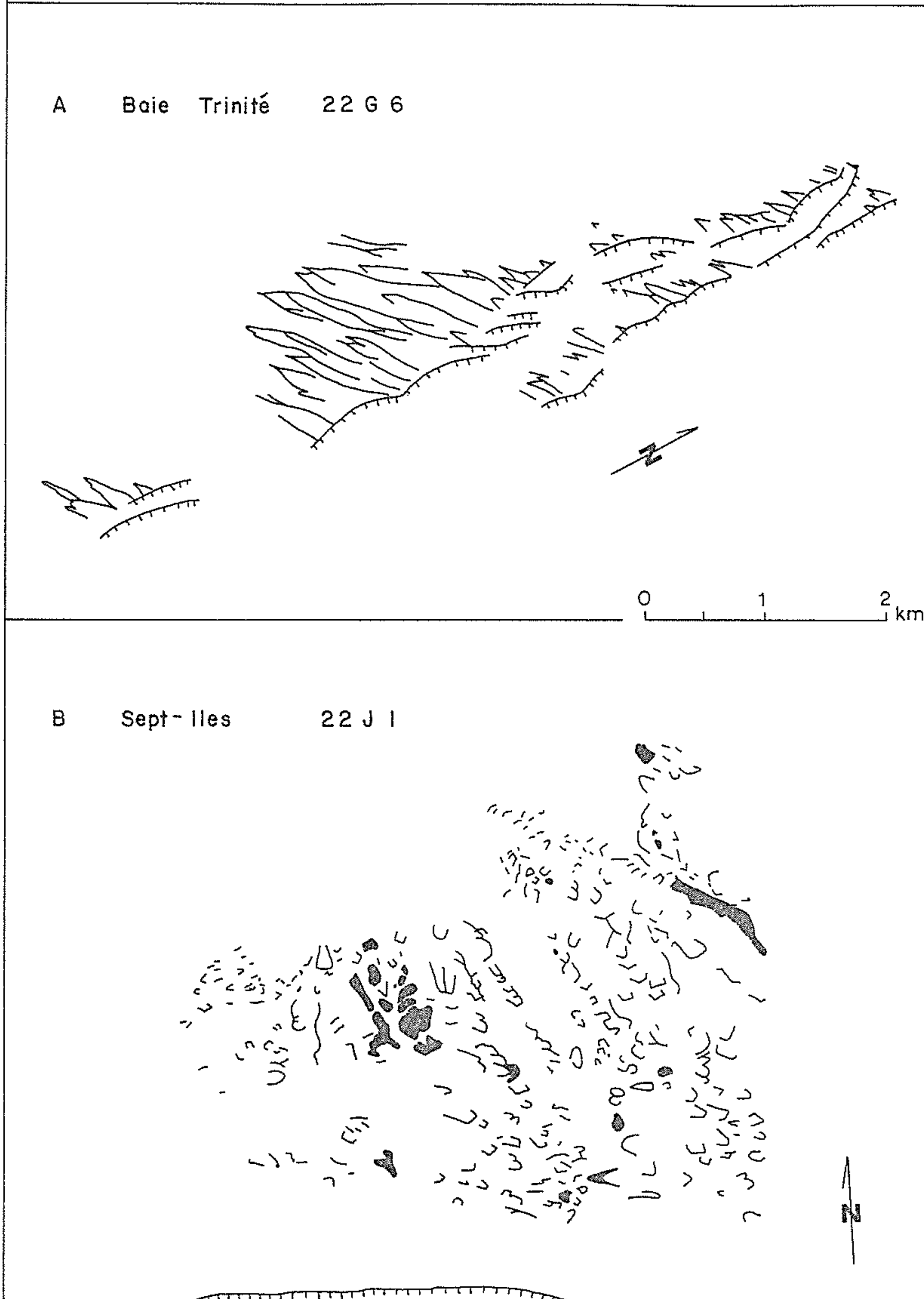


Figure 5-2 Small parabolic dunes west of Baie Trinité. Map unit 7.

The modal size is between 0.7 mm (−0.5 ϕ) and 1.0 mm (0 ϕ), whereas in typical aeolian dune sand the mode lies in the 0.125 to 0.06 mm (3.0 ϕ to 4.0 ϕ) range. The material consists principally of quartz, with some feldspar and a few garnets and amphiboles. Grains are abraded and frosted, and quartz grain edges are rounded.

The location of the dunes, and their geometry, which resembles those described by Cooper (1958), suggest that they are simple blow-outs which originated along beach ridges exposed to northeasterly winds prior to their stabilization by vegetation. The coarseness of the sand and its mineralogical similarity to adjacent parent beach material indicate that the dunes may be simply accumulations of sand, produced by saltation and accretion of sand moving very near the ground over very short distances, rather than true dune forms created by the selective entrainment of the light or fine-grained component and their ultimate deposition by avalanching over a dune front. This view is supported by the bulk density of the dune material (1.58 g/cc) which is the same value as compacted beach sand in the area, and which is denser than sand sedimented by free-fall in air over an avalanche face (free-fall density ~ 1.3 g/cc). In addition, the apex slopes are at eight degrees, much less than avalanche angles of repose. The data thus suggests that there has been little reworking or modification of the parent beach material, although the winds were persistent enough to produce well formed blow-outs. Sand grains within the dune field are frosted and rounded, characteristics commonly associated with intense aeolian activity, but these attributes are also characteristic of the parent beach material at this site.

Sept-Iles dunes

The dunes at Sept-Iles consist of about 300 irregularly shaped hills and ridges covering an area of 25 km^2. Crests are very rounded; sideslopes stand at angles up to 20°. The relief varies from two to six metres. Internally, the dunes consist principally of tabular cross-strata; lower bounding surfaces are erosional, with angles varying from 2° to 20°. Avalanche-type beds inclined up to 34° are common. Longitudinal sections show that the structures are draped, so that the uppermost crest lies to the west of lower crests, which implies that sand-moving winds originated in the east (cf McKee and Tibbits, 1964).

As in the case at Baie Trinité, the dunes consist of yellow-brown (10 YR 6/8) siliceous sands, which have dull or frosted surfaces, but in the Sept-Iles field there is no trace of the heavy minerals found in the underlying beach material. The sands are slightly finer than the parent beach material and not so well sorted. They are substantially finer than those at Baie Trinité (modal size is between 0.25 mm (2 ϕ) and 0.125 mm (3 ϕ)). The finer nature of the material, absence of heavy minerals, lower density, and high-angle avalanche type bedding suggest that the wind was an active agent here.

Because of the chaotic geometrical configuration of the dunes as seen on the ground, an orientation analysis was carried out by measuring the lengths and orientations of dune segments, both manually, (which is somewhat subjective) and by passing coherent light through a photograph of the dunes to produce a Fourier pattern (which is objective but difficult to interpret by itself). The resultant circular frequency distributions were analysed by Tukey X^2 tests, as described by Middleton (1965), and vector analysis (Pincus, 1956). The results indicate:

1. there is a statistically preferred (0.01 level) orientation in the N90°±15°E sector. Internal structure indicates that the sense of the movement of sand was from east to west.

2. the most elongated dunes are the ones which lie in the direction of

preferred overall orientation. According to Bagnold (1941) this means that both the prevailing winds and storm winds therefore originated in the east (this same condition prevails in summers at present). The biaxial dune forms, barchans and U-shaped dunes make only minor contributions to the pattern because their orientations are inconsistent.

The Sept-Iles field appears to be a relict, true aeolian form resembling true desert dunes rather than coastal blow-outs. The field is interpreted as being basically a seif field, since degraded. The degradation might have been initiated by changing directions of prevailing winds prior to stabilization by vegetation.

Since no dune fields appear on terraces below 50 m ASL, the emergence graph on Figure 4-21 (p. 129) can be used to estimate the time of cessation of aeolian activity. On this basis, dune development appears to have ended between 6500 and 7500 years ago. This period corresponds to the termination of dune formation in other parts of the St. Lawrence Lowlands (Lambert, 1972).

5.2 Bog Deposits

Types of organic accumulations

The humid microthermal climate of the North Shore encourages the accumulation of peat wherever subsurface drainage is restricted. The climate is warm and humid enough to encourage the development of substantial biomass, but sufficiently cool to prevent rapid decomposition (Allington, 1961).

Topogenous bogs occupy kettle holes and small bedrock basins. These consist primarily of lake infillings of sedge and floating Sphagnum, but some quaking spruce-forest bogs also exist. The total area occupied by bogs of this type is very limited.

Meadow-type bogs occupy areas below the marine limit where level bedrock benches are veneered by a shallow layer of sand. On air photos, bogs of this type appear as smooth, even-toned mats. These are located along the forelands west of Ste - Marguerite (Figure 5-3) and between Rivière Vachon and Rivière de la Trinité.

Ombrogenous string bogs, by far the most extensive areas of boglands, lie atop the delta formations between Port-Cartier and Moisie (Figure 5-4), where broad postglacial marine terraces are best developed. The largest continuous bog, at Sept-Iles, covers 920 hectares (about 2500 acres). Drainage in these areas is restricted due to the lack of relief, the presence of a hardpan in the B-horizon of the soil and/or the proximity of silty or clayey substrata. The water table is at, or very near, the surface. On air photographs these ombrogenous bogs on the deltas have vermiculoid III surface patterns in the Radforth classification system (Radforth, 1969). The profiles are slightly convex.

Less extensive bogs are located along present and former drainage channels and along swales behind the present beach near Moisie. In these situations, a thin mat of vegetation is floating on water.

Bog depths were determined using a hand auger and Hiller corer. The maximum thickness was four metres, near Ste - Marguerite. At Sept-Iles the bogs are usually less that three and a half metres deep but the depth is highly variable because of irregularities in the surface of the underlying deposits. The bog surface consists chiefly of live sphagnum, but sedge, vaccinium, ericads, birch and willow are locally important. The active growth layer is underlain by peat which grades from an upper zone of brown, watery, organic-rich matter through a fibrous and compact brown peat to a basal zone of amorphous black gyttja.

Figure 5-3 Meadow-type bog (map unit 9c) along the hydro line at Pointe Jambon. Foreground is sand veneer (map unit 6b).

Figure 5-4 Extensive string bog (map unit 9b) east of Rivière Ste-Marguerite. Photo also shows the flat coastal plain, and southern edge of the upland.

Nature of the peat

Peat samples were extremely difficult to extract because the cutting edge of the Hiller borer (and shear vanes) became entangled in the peat fibres; as a result the following description is based on only one section of core, which consisted of brown, very fibrous, only slightly decayed shrub and moss remains. The water content was 1150% of the dry weight and the pH of the excess water was 5.0. Plant remains and twigs were aligned horizontally along planes of deposition but fibres between layers were intertwined sufficiently so that shear resistance was about the same in both horizontal and vertical directions. (This sample therefore has shear properties which are markedly different from samples obtained from the Parry Sound Defence Research Board test bogs which have anisotropic shear properties). Based on field observation, the peat in the large bogs of the coastal plain is highly compressible. On Cook's graph (Cook, 1956, fig. 2) relating water content and compressibility, the compression index (i.e. the slope of the e/log p curve) of this sample should be about 13. The fibrous nature of the deposits and the ease with which water can be expelled by squeezing suggests that the peat will drain and compress readily when a load is applied. No settlement is apparent along portions of the highway that cross organic terrain where side ditches have been dug to drain the roadway, but corduroy lumber roads set on the bog surface have undergone differential movement.

Pollen records

The stabilization of aeolian dunes suggests that organic deposits began to accumulate on the exposed delta surfaces shortly after 7500 BP, although the earliest absolute dates on organic materials, from basal gyttja in two outwash ponds near the marine limit at Lac Walker and Sept-Iles are

6960 ± 300 BP (GSC - 1811) and 5460 ± 100 BP (GSC - 1821) respectively.

In 1972 R.J. Mott (GSC) collected surface grab samples from a number of ponds in the area and cored the organic deposits in the two ponds mentioned above. Since then he has constructed pollen frequency diagrams from the Lac Walker data (Mott, 1976). His results indicated that "the forests of the area were boreal and dominated by conifers, birch,and alder throughout the 7000 years represented by the core. The earliest forest type recorded (LD5) suggests that alder was more abundant than at present, possibly because the sandy outwash delta may have been a low wet area at that time. About 7000 years ago there was a dramatic increase in abundance of balsam fir (LD4), which lasted until 6400 BP. Concident with the decline of balsam fir was an increase in birch followed by an increase in spruce. About 5000 years ago spruce and birch abundance increased further, in a response to more favourable growing conditions. The forest composition remained much the same up to the present day but the declining pollen influx values after 3500 BP may indicate deteriorating growing conditions."

The data from Matamek (Bowman, 1931), about 15 km beyond the eastern boundary of the field area, shows a similar vegetation sequence, but Bowman's profile might extend further back in time, since his balsam fir maximum near the base is preceded by birch-alder and sedge zones. The hemlock peak in the Matamek profile which has been correlated with Potzger's Q-4 zone (Terasmae, 1969) does not appear in either the relative or absolute pollen profiles analysed by Mott.

Although Mott cautions that the Lac Walker zones "may be unique to the site and therefore do not necessarily have a regional significance", his chronology and vegetation sequence are fairly similar to the results of Ignatius (1956) in the Mistassini area, who reports a basal alder zone, dated greater than 6960 BP (Y-223), followed by a pine-spruce zone (6730 BP; Y-222) with a later birch maximum, a spruce maximum, and a final spruce decline.

The Lac Walker profile differs in taxa and chronology from others in Labrador (e.g. Morrison 1970) and in the Gaspé to the south (Potzger, 1953) although the penultimate zone in all of these suggests that a warmer, moist period preceded the present cooler, wet climate.

5.3 Alluvium

The term "alluvium" is used here to denote those deposits resulting from fluvial accretion in postglacial time. Alluvium forms the surficial deposit on low terraces which flank most of the river valleys, as well as modern flood plain, point bar and channel deposits. The material consists of cross-stratified, current-bedded gravel, gravelly sand, and sand, most of which is only moderately well sorted because of admixing by fine-grained overbank deposits.

Gravelly alluvium is prevalent on terraces that developed where rivers incised and redistributed former glacial and valley fill deposits. Gravel also covers the bottom of raised meander scars which are well developed on the east side of the Ste-Marguerite delta.

One of the most extensive sand-and-gravel alluvial deposits is the meander scroll complex along the lower Moisie River, where a set of crescentic point bars has developed along a slip-off slope which is two kilometres wide and extends vertically from 46 m to present sea level. Grain sizes range from cobbles along the basal riverine side of the bars to silts which overspill into the intervening swales during flood stages.

Sand and gravel are also encountered where river gradients decrease abruptly. The most extensive deposits are located at heads of the large lakes - Lac Pentecôte, Lac Walker, and Lac Pasteur - but significant deposits are also found within the uplands at places where small streams leave the bedrock and enter flat-bottomed outwash-filled channels. In a similar fashion, the building of dams along Rivière Ste - Marguerite and Grande Rivière de la Trinité has altered the natural base level of these rivers, the result being increased alluvial accretion at the heads of the artificial lakes.

Shifting bars of fine, grey micaceous sand have choked the lower reaches of the Moisie and Pentecôte Rivers, as a result of erosion of thick postglacial deltaic deposits. Along the Moisie, the shifting sands fill the channel below the point where three and a half million cubic metres of sediment entered the river during landslides in 1959 and 1966. Along Rivière Pentecôte the bars are prevalent between the first falls and the mouth of the river.

6. GLACIAL AND POSTGLACIAL HISTORY

6.1 Effect of Glaciation on the Bedrock Topography

Bedrock state prior to the last glaciation

The physical state of the bedrock surface has probably not been altered greatly by glacial activity. This view is directly opposed to the ideas of some investigators who have argued that a thick regolith overlay the bedrock prior to glaciation; their evidence is based primarily on the presence of pockets of weathered rock which lie in areas protected from glacier erosion, and to a lesser extent, on the absence of unstable minerals in certain tills (cf Gravenor, 1975, p. 600). Within the field area, one pocket of disintegrated bedrock is located in anorthosite at Lac Caché five kilometres southwest of the Rivière Ste Marguerite dam, and more widespread occurrences are common in the area between Port Cartier and Lac Pentecôte. The depth of disintegration, exceeding four metres at Lac Caché, appears to be too great to be explained as postglacial weathering. Nevertheless, the coarse texture and mineralogical immaturity of the till and complete absence of clay weathering products within the till suggest that a deeply weathered mantle was not widespread on the North Shore.

The absence of a deep layer of till further suggests that a weathered mantle (prepared material) did not cover the surface prior to the last glaciation, and that the erosive effect of glaciers in the field area was relatively minor.

It has also been argued that glaciers extensively eroded a substantial pre-existing Paleozoic cover from the Shield (e.g. White, 1972). This argument is partially based on the presence of Paleozoic outliers, such as those reported by Ambrose (1964) in the Manicouagan and Otish Mountain areas.

However, for the North Shore at least, petrological and mineralogical evidence negates this hypothesis, since no rock fragments or mineral suites with Paleozoic affinities were identified within the tills. The sedimentary cover must have been stripped prior the last glaciation.

Topographic effects of glaciation

Hare (1959) has noted that, although the central Labrador plateau shows signs of intense glaciation, the "clearcut glacial grain" of that landscape disappears at the northern edge of the Laurentian Upland. Several lines of evidence indicate that the preglacial topography of the Shield, with its mammilated hills and large, broad valleys, has not been substantially altered by the last glaciation:

1. The large valleys which are prominent relief features in the landscape have preglacial, not glacial origins. Cooke (1929) has shown that the major river systems have their origins in Tertiary and pre-Tertiary times. More recent borehole evidence shows that bedrock base levels of these valley floors lie far below sea level, which suggests that these valleys are integrated with the proto-St. Lawrence drainage and the Laurentian Channel. These valleys have since been subjected to overdeepening by glacial scouring, but the general preglacial form of the valleys, and the integrated drainage pattern have remained intact.

2. Many of the small rivers and streams, instead of being deranged as a result of glacial activity, are adjusted to structure; neither glacial erosion nor subsequent deposition disrupted the original stream pattern, except where major outwash channels were in-filled with sediment.

3. The glacier neither eroded incompetent bedrock in the Lac Dupont-Pentecôte area (which is an exposed upland), nor did the force of the overriding ice rearrange the disintegrated bedrock. (Small pegmatite dykelets

which extend through the incompetent material have not been displaced.) In this area, at least, continental ice apparently had little capacity for erosion.

4. Because the till cover is generally very thin there are few depositional land forms to alter the overall preglacial appearance of the landscape.

Although the major aspects of the landscape have not greatly changed, the microtopography has been altered and limited areas have been substantially eroded:

1. Where bedrock is fine-grained, it is highly polished and striated; coarser granite surfaces have been roughened and chipped.

2. Small-scale grooved and streamlined forms are present over the upland and beneath glacio-fluvial gravels. Streamlining is most obvious near the coast at Pte des Monts, Port Cartier, and Rivière Pentecôte where waves have washed away the overburden.

3. Rock bosses along the powerline north of the Baie des Sept-Iles show glacial plucking on a larger scale (about six metres vertically). Here joint blocks on the southeasterly side of the bosses appear to have been removed by frost riving during regelation, a mechanism proposed by Carol (1947) and later demonstrated by Kamb and La Chapelle (1964).

4. On a larger scale, glaciation has altered the landscape by trimming some of the large preglacial valleys, creating faceted spurs and hanging valleys, the most prominent of which are indicated on the accompanying surficial geology map.

6.2 Directions of Ice Movement

General statement

Unlike the south shore of the St. Lawrence, there is no controversy over the general direction of ice flow over this area. The generally accepted concept is that a major centre of Laurentide ice flow was located in central Labrador-Ungava, which would have produced north-to-south ice movement over the field area. Although most field data support this consensus, Faessler (1942a) and Grieg (1945) have mapped striae indicating ice movements from northeasterly and northwesterly quadrants as well. Data presented earlier in the text or on the accompanying map is summarized and evaluated in this section in order to document more fully the ice flow indicators along the North Shore, and to sort out the importance and order of occurrence of the varying flow directions.

Field observations of striae, chattermarks, grooves and plucked forms were recorded, and the orientation of faceted spurs with hanging valleys were plotted from air photos. Other criteria used to determine ice flow directions come from the till itself; these are (1) till fabrics (2) the orientation of morainic ridges and (3) indicator mineralogies.

Striae and grooves

A compilation of striae and grooves in the field area appears on the surficial geology maps (in pocket). The distribution of these observations is mainly a reflection of accessibility. Most of the striae were measured on broad, approximately horizontal surfaces so that regional, rather than local, ice flow directions could be inferred. Generally, the coarse-grained rocks carry no well-defined striae but they do preserve linear roughenings, chattermarks and grooves. Where numerous quasi-parallel striae were observed on a single exposure, the most frequent orientation was plotted. The maximum measured divergence from this modal value was 15°. In the areas where many crossed striae were observed it was difficult to assign relative ages in most cases; the conclusions which were drawn from cross-striae data are based on the few cases where the first striation is distinctly disrupted by a deeper crossing one.

The striae and micro-groove data suggest that a major ice lobe flowed over the entire area from the north-northwest. On the Sept-Iles map sheet, fluted and grooved surfaces are consistent with striae data. Plucking was observed on the south side of grooved gabbroic bosses, in accordance with a flow from north to south. Indicators on the Cap Chat map sheet also suggest movement from the north and north-northwest, but in the southern coastal portions of the sheet there is evidence for directional changes. In the Mistassini and Godbout areas ice was apparently channelled along preglacial valleys, producing striae and grooves bearing east-southeast; and at Pte des Monts, where the Laurentian trough continues east off the map sheet, crossed striae and metre-high streamlined plucked forms are well developed. Here, the most abundant striae bearings are west, north-northwest, and west north-west (see Figure 6-1). The west-east ones definitely intersect the previous sets in several places. Streamlining is consistently west-east with definite plucking on the easterly side. To the northeast at Baie Trinité, however, plucked streamlined forms suggest that an ice flow from the southwest (i.e. splaying northwards from the Laurentian trough) predate the main southeasterly flow; frequent chattermarks found only on the northerly side of the stream-lined forms suggest that tools in the sole of the glacier later marked the rock bosses as ice advanced from the northwest. If the southeasterly flow represents the main ice advance, then these streamlined forms could have been produced by an earlier ice flow down the St. Lawrence valley.

The evidence presented here indicates early ice flow down the Laurentian trough, followed by ice movement toward the south-southeast over the entire area. In the southern extremity of the field area there was a later directional change to an easterly flow. This directional change may have been a result of deflected flow produced by drawdown along the Laurentian Trough at a time

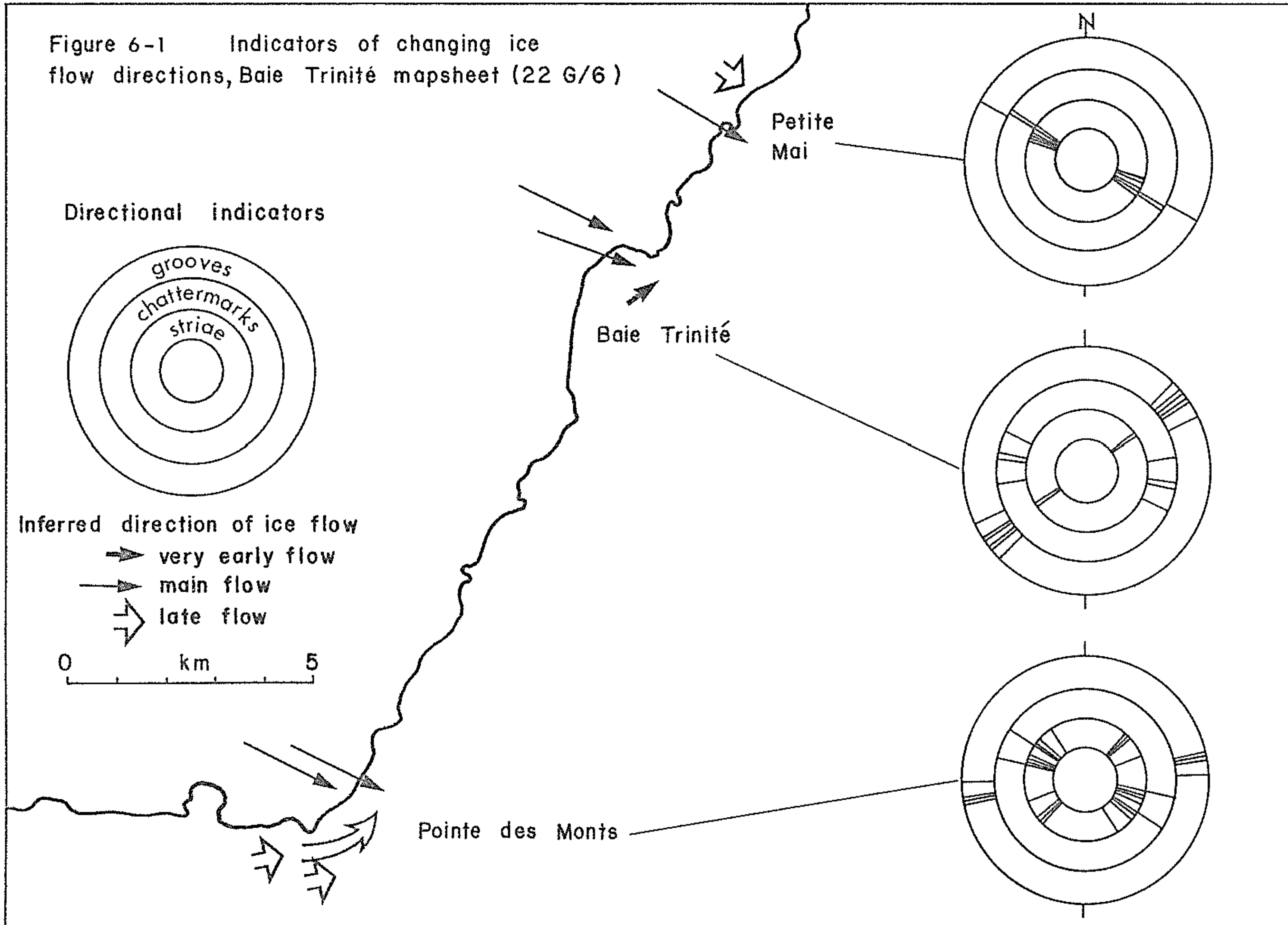


Figure 6-1 Indicators of changing ice flow directions, Baie Trinité mapsheet (22 G/6)

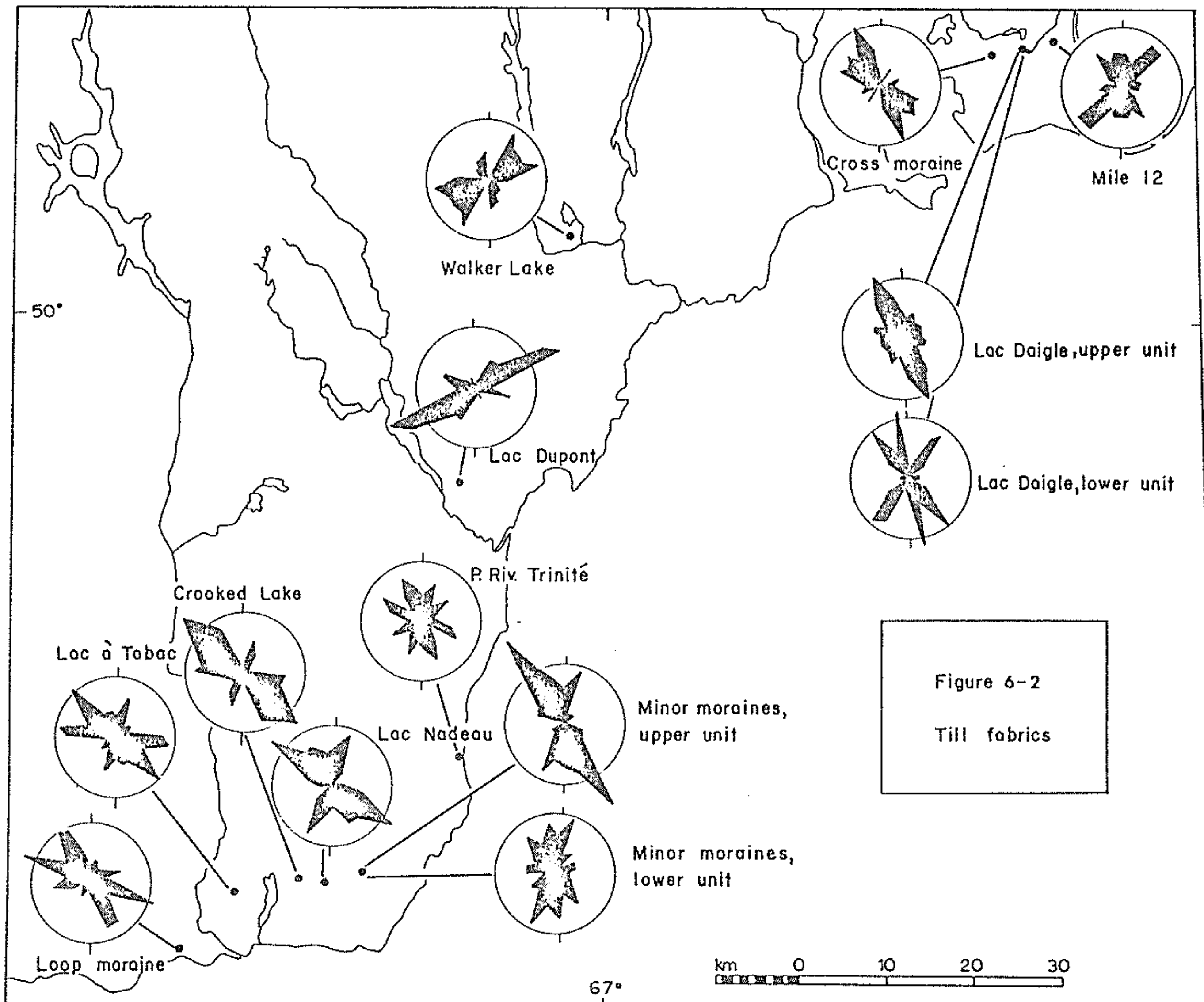
when the ice sheet was thinning (i.e. a topographic effect). An alternative (but less likely) explanation is that easterly deflection was caused by impingement of an independent ice sheet flowing northwards from the Gaspé highlands towards the trough.

Faceted valley walls and hillforms

Large scale indicators of flow, as determined by air photo interpretation, are consistent with the striae survey in the areas covered by field inspection. To the north, valleys oriented north to north-northwest have the deepest, straightest, sidewalls and faceted spurs, but shallower facets are also common in the northeast-oriented valleys. This observation suggests that at some stage(s) there was substantial topographic control over flow direction, and that the ice was channelled into the larger pre-existing valleys.

Till fabrics

Although till fabrics show general trends they do not provide a good indication of regional ice flow directions in the field area (Figure 6-2). Problems associated with the fabrics and their interpretation are discussed in Appendix B. In the Cap Chat map area most fabrics show preferred orientations in the northwest quadrant but there are a number of exceptions. The polymodal fabric at Petite Rivière de la Trinité may be the product of modification of the till by wave action. The easterly fabric at Lac Dupont may represent a cross fabric (assuming that till at this particular site was solely englacially transported and deposited as basal melt-out). The fabrics from sites within the Sept-Iles map sheet show preferred orientations in both northwesterly and northeasterly quadrants. The northeast modes in the lower unit at Lac Daigle and at Mile 12 could be related to ice flow from the



Circles inscribe frequencies of nine per cent

Moisie Valley; but they might also be related to smaller scale interparticle stresses in the tills (i.e. local anomalies around boulders) rather than to regional changes.

Morainic distributions

The bearing of morainic ridges investigated on the ground and mapped from aerial photographs can be used as indicators of late glacial flow if they are assumed to be parallel to active ice fronts during glacial recession: these directions represent flow during retreat and not during maximum glaciation. The orientation pattern of the moraines indicates ice flow directions similar to those suggested by striae. At Sept-Iles and on the northern part of the Cap Chat map sheet they are normal to a north-northwest source. In the southwest part of the Cap Chat sheet they trend southwest-northeast; there is no evidence of a completely easterly flow, as indicated by striae. From the distribution of these ridges it appears that ice melted back in a northwesterly direction over the map area. The string of moraines between Lac Dionne in the west and Lac Daigle in the east may represent the configuration of a retreating ice front. It seems that the retreating ice margin did not follow the lines of the present coast; rather, the area south of Pentecôte was deglaciated earlier than coastal areas to the east.

Petrological indicators

The geological map of Quebec indicates that there are no unique lithological or mineralogical types with distinctive source areas within the Sept-Iles and Cap Chat map sheets. Beyond the map boundaries there are distinctive sandstones and quartzites in the Otish Mountains and metamorphic sequences in the Lac Mistassini region to the northwest, but no traces of these were found in the till.

Although lithologies repeat in the field area, studies of till mineralogy and pebble lithology indicate that, once bedrock boundaries are accurately known, then local ice flow directions can be inferred from heavy/light mineral ratios and the hornblende/pyroxene ratios in the till above bedrock contacts (providing there is no overriding from more than one direction). The mineralogy of the Godbout and Lac à Tabac tills indicates ice flow across a nearby ultramafic body lying to the northwest, which agrees with other directional data. Most of the other till samples reflect the lithology of underlying bedrock types because samples were taken from the middle of the rock type areas, not the edges.

Summary of evidence

At one site near Baie Trinité there is evidence of early ice flow from the Laurentian trough towards the northeast, but the major direction of ice advance over the entire map area was towards the south-southeast, with some local deflections into large preglacial valley systems and around topographic prominences. There was a later directional flow due east in the south part of the map area. The restriction of this change to areas adjacent to the Laurentian trough suggests a drawdown effect. During the retreat phase ice flow persisted from the northwest; hence, the southwest part of the map sheet was deglaciated before those areas to the northeast. The presence of multiple modes in some till fabrics may indicate that there was over-riding and very local lobing during retreat.

6.3 Evolution of the Landscape

This section attempts to reconstruct major events related to glaciation and postglacial evolution of the landscape. The account is based on an interpretation of the sedimentary materials described in the preceding sections.

Because good stratigraphic and chronological control of events are lacking, the following interpretation is somewhat speculative.

Glaciation

Age

Although earlier glaciations must have contributed to landscape development (e.g. in the removal of a weathered mantle) the materials and landforms studied are considered to be the product of the Wisconsin glaciation. Since there is no stratigraphic evidence for more than one till sheet in the area, and consequently for more than one ice advance, the area may have been continually ice covered during most of the middle and late Wisconsin. The initiation of glaciation whose events are recorded in the field area probably occurred at least 50,000 years ago; i.e. it covers the period following the St. Pierre interval in the St. Lawrence Lowlands.

Ice flow directions

In 1896 A.P. Low postulated that the centre of the Labradorean ice sheet was near 51°N 70°W, an area of heavy snow accumulation in present times, (about 100 km due west of Lac Manicouagan), but field evidence indicates that the prevailing direction of ice flow over the entire area was from the north-northwest, in keeping with the more recent theory that the main dispersal area was the central Labrador plateau. There is no evidence within the field area or in the adjacent Nipissis map area to the north (Hogan, 1971) to suggest that ice flow from the various local centres which existed at the end of the last glaciation (Hughes, 1964; Kirby, 1961; Laverdière, 1967) reached the field area. All deviations from the prevailing northwesterly flow can be explained as topographic effects, mainly related to the presence of large, preglacial valleys. These topographic controls became especially important at the beginning and toward the end of glaciation, when drawdown into the Laurentian Trough induced an easterly ice flow component over the southern part of the Cap Chat map-area.

Character of the ice

Indirect field evidence suggests that for much of its duration the ice sheet may have been frozen to its base. There are virtually no large scale classical erosional forms and the till sheet, the depositional product of glacial erosion, is less than two metres thick. This negative evidence suggests that the ice sheet, although it may have covered the area for at least 50,000 years, was generally incapable of erosion. Toward the end of the glacial episode, however, the ice sheet became wet based, and basal melt-out deposited a till which clearly shows the influence of water in its texture and structure.

The ice was continually in an 'active' state, (i.e. plastic and flowing) even during its retreat. There are no remains of stagnant ice features, except for a few kames. This situation is markedly different from the widespread stagnation which occurred on the Labrador plateau.

A possible mechanism for deglaciation

It is suggested here that the mechanism by which break-up of the ice sheet occurred in the Gulf may be related to ablation of the ice sheet and coincident sea level rise. Once the depth of water in the Laurentian Trough exceeded 10/9 the thickness of the overlying ice, the ice in the trough would become buoyant (assuming the density of ice is 0.9 g/cc). Because ice shelving conditions are known to be climatically unstable for temperate glaciers (Denton _et al._, 1971; Mercer, 1961), and mechanically unstable when water depths change (Hughes, 1975), the result of a sea level rise and/or general ablation during the late Wisconsinan would be the massive break-up and rapid retreat of the ice front up the Laurentian Trough.

Evidence from southern Newfoundland suggests that break-up of ice in the Gulf occurred about 13,500 years ago (Brookes, 1969; GSC-1074). Ice then backwasted by calving at a rate of 500 m/yr., resulting in a lead which extended to Quebec City by 12,400 BP (date from LaSalle, 1972; GSC-1533)[1].

At the time of break-up, the equilibrium thickness of ice in the Laurentian Trough south of Pte. des Monts must have been about 450 m; the base of the trough in this area lies between 300 and 350 m below present sea level. About 13,500 years ago it was about 400 to 450 m below the sea level of that time (because there has been 100 m of emergence in that area). Therefore, when the ice was just at the point of flotation it must have had a maximum thickness of 440 to 500 m (i.e., 10/9 x 400 and 450).

Once shelving conditions began off Pte. des Monts, ice from adjacent grounded areas to the north would be drained (or drawn-down) to feed the wasting ice shelf, which was tending to thin and spread out under its own weight. Because of this effect the grounded ice between Baie Trinité and the western margin of the map area was probably fairly thin.

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[1]There is no direct chronologic control for the time of deglaciation of the Godbout part of the map-area. Deglaciation of the trough may have occurred as early as 13,500, but despite this rather old date, shell dates from the Baie Comeau area (GSC-1565, Lowdon and Blake, 1973), immediately west of the Cap Chat map sheet, would suggest that deglaciation (of the land mass) may have occurred as late as 10,000 BP. Possibly the trough cleared early but ice remained on the land nearby for a long time. At any rate, the timing of ice withdrawal from the narrows of the Laurentian Trough is rather important because it controls the earliest date for a marine lead into the St. Lawrence Lowlands; the chronology is difficult to sort out without dates from adjacent parts of the North Shore and Gaspé. A series of dates intermediate between the 13,500 and 10,000 dates have been reported from Champlain Sea areas and from the Gaspé (Locat, 1976).

In the Sept-Iles area, however, which is separated from the trough by a shelf between 30 and 40 km wide, the thickness of the ice predicted by Nye's and Hollin's equations would be about 830 m (Nye, 1952; Hollin, 1962). In the Sept-Iles area it is therefore suggested that the ice remained plastic, and grounded offshore for some time after the southwest part of the Cap Chat area was deglaciated, and the style of deglaciation in its initial stages was somewhat different from that hypothesized for the southern Cap Chat region. South of Sept-Iles, the sea presumably abutted against a wall of grounded ice. Theoretical calculations of uplift, and the absence of field evidence for a marine transgression indicate that postglacial uplift exceeded sea-level rise; therefore, there must have been a continual lowering of sea level relative to the ice wall. Since the glacier retreated up the slope of the Laurentian massif, at some point the sea and ice mass must have become separated. This event is reflected in the deposits around Lac Daigle, where interfingerings of till, outwash and beach material exposed infront of a portion of the Daigle moraine show the relationship between a terrestrial ice front and sub-aerial coastal activity.

It is proposed that deglaciation and separation occurred between 10,000 and 9500 BP in the Sept-Iles - Daigle Lake area. The oldest minimum date for deglaciation 9350 BP (Qu 209 at 123 m) is based on a shell sample very near the level of the highest beach ridges. It is supported by a shell assemblage in deep water marine clays dated at 9140 ± 200 (GSC-1337; Lowdon _et al._, 1971) found at a lower elevation (76 m ASL).

When the ice and sea became separated, evolution of the landscape proceeded along two independent lines: recession of the ice from the land mass, and emergence of the coastal area.

Recession of the ice to the Labrador Plateau

Formation of the Baie Trinité minor moraines

The small, discontinuous morainic ridges west of Baie Trinité are the oldest moraines in the field area, being formed between 13,500 and 10,000 years ago when part of the Laurentian Trough south of Godbout was ice free. The moraines consist of diamictic till lacking sedimentary structures but having fairly well-defined fabrics, except for the extremities of the more southerly moraines, which were eventually exposed to wave action and reworked. The moraines are interpreted as being sub-glacial terrestrial deposits. I suggest that, at the time of their formation, the ice mass overlying the Pte des Monts area was fairly thin and brittle because of its proximity to a grounded terminus directly south or ablating ice shelf in trough. The moraines were the result of eventual basal meltout of material moved along shear planes behind the area of brittle (nonflowing) ice. The edges and upper exposed surfaces of the moraines below the postglacial marine limit were reworked by wave activity.

This interpretation is similar to the mechanism proposed by Elson (1957) to explain "washboard moraines". The concept differs from that proposed by Mawdsley (1936) to account for "washboard" moraines in the Chibougamau area in that no hydrostatic upthrust is required to form breaks in the base of the glacier. There is no evidence of their being DeGeer-type push moraines because the distal and proximal flanks are symmetrical. The deformational flow structures which Hoppe (1959) and Andrews (1963) have associated with small moraines are also lacking; their limited occurrence militates against their being "annual" moraines.

Formation of the Daigle-Laurentian moraines

Following retreat of the ice from the Baie-Trinité area the ice front receded in a northwesterly direction until about 10,000 BP when it was approximately parallel to the coast near Sept-Iles and about 35 km inland north of Godbout on the Cap Chat map sheet. The Daigle moraine, the remnants at the valley heads farther south-west, and the disconnected upland moraines on the Cap Chat map sheet that are in line with these are the only major moraines formed in this area during deglaciation. Their morphology and physical properties have been previously described. Their lobate nature suggests that they were formed on land. There is no evidence to suggest that these moraines were the product of a readvance; therefore, they are interpreted as being generated by minor fluctuations along the retreating ice front. Their genesis may be related to some sort of "quasi-stationary" ice front created when the sea and ice mass separated and calving ceased, because for much of their extent (between Rivière Moisie and Rivière Pentecôte) the moraines lie directly above the marine limit. The upland moraines may represent the extension of this ice front on more elevated terrain to the west.

General retreat to the Plateau

Following deposition of the Daigle-upland morainic system, the ice retreated actively to the rim of the Labrador Plateau, where it split up into local centres and finally stagnated. The only kame deposits in the field area are limited to the southern part of the Lac des Rapides basin, where a small ice remnant could have become separated from the main ice mass and stagnated in the topographic basin. Small amounts of drift were carried short distances near the sole of the glacier, judging by the freshness of the clasts and their petrology, and till was deposited as basal meltout to form a thin cover over most of the field area. The glacier at this time was very wet-based, and structures within the till suggest that it was deposited as a slurry.

The work of Grayson (1956) indicates that ice had retreated north of the margin of the plateau at least 8000 years ago, and Morrison's work (1970) shows that it totally disintegrated by 6000 BP. The resultant rate of retreat is about 180 m/yr, a value comparable to the calculations of Antevs (1925) and Flint (1955) for Ontario. The retreat to the plateau was probably fairly steady (without fluctuations) - no other moraines were found that are large enough to be discernible on the air photos. The absence of morainic ridges is probably a result of:

1. continuing extending internal glacial flow, downslope. Morainic development is commonly associated with compressive flow up shear planes.
2. A cold ice sheet covered the area under consideration for much of the Wisconsin, and then underwent a steady retreat as climate ameliorated. There were no major readvances to push material into moraines. Even at deglaciation when subglacial water was abundant there would be little chance of a surge because the melt water was free to drain downslope.

Outlet glaciers occupying major valleys may have been present for a short time, since truncated spurs are found along E-W - oriented valleys as well as N-S ones parallel to the major ice flow directions. Fiord glaciers, however, must have been short-lived:

1. with a wet-based glacier such as existed at the close of glaciation, an ice shelf is theoretically dynamically unstable. Mercer (1961) has shown that temperate glaciers in lowland valleys are also climatologically unstable because extensive rapid ablation occurs once the firn line rises above the level of the ice shelf, rapidly depleting the fiord of a vast area of ice.
2. there is no morphological evidence such as lateral moraines to suggest the presence of fiord glaciers in the valleys, nor is there any sedimentological evidence of ice-rafted material, although evidence for this may exist beyond

the field area.

The formation of the major outwash plain north of Sept-Iles appears to have been approximately contemporaneous with high sea level since the material grades to sandy-textured beach sediment. At this time coarse outwash from the rapidly-receding glacier was infilling the preglacial Daigle distributary valley. Southward-flowing meltwater breached the Daigle moraine, rapidly lost competence on the distal side as the confining valley walls gave way to open coast, and deposited the coarse fraction of its sediment as an outwash fan grading to baselevel at 130 m ASL. Similar events transpired in the Riverin and Vachon river valleys where moraines were also breached and partially eroded.

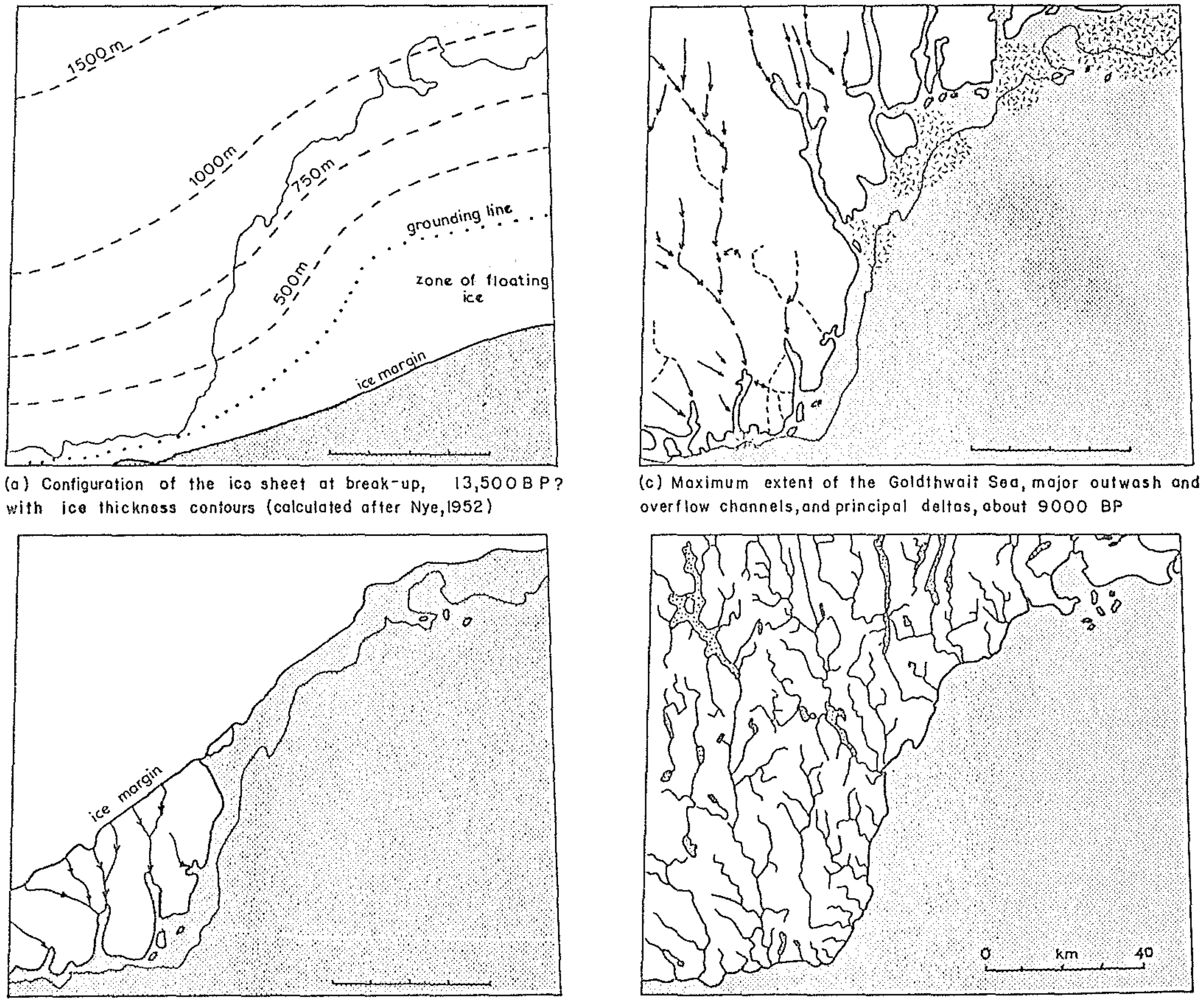
As the ice sheet retreated northward, vast quantities of sediment-laden meltwater were quickly channelled and carried down the slope of the Laurentians in preglacial valleys, and in a series of meltwater channels. The main routes are shown in Figure 6-3. Since this meltwater was able to flow in previously-existing channels, most of the outwash deposits (and occasional scattered esker remnants) are found in association with river valleys. The coarsest material was deposited in the upper parts of valleys. Sand and fines partially infilled the inundated front valleys and built large deltas at the front of the main escarpment. Sedimentation was very rapid, as indicated by the vast quantities of material forming the valley fill and estuarine deltas at a time when sea level was still very high. As the ice retreated, successive terraces were incised into the raised outwash deposits.

Goldthwait Sea episode

Configuration and extent of the Goldthwait Sea

The Goldthwait Sea refers to areas formerly submerged by postglacial

Figure 6-3 Evolution of the landscape



(a) Configuration of the ice sheet at break-up, 13,500 B P? with ice thickness contours (calculated after Nye, 1952)

(b) Ice margin, meltwater channels, and the Goldthwait Sea, about 9300–10 000 BP

(c) Maximum extent of the Goldthwait Sea, major outwash and overflow channels, and principal deltas, about 9000 BP

(d) Present configuration of the coast, and major drainage channels

extent of Goldthwait Sea   channels: ⟶ outwash, --- overflow   principal deltas marine inundation in the Gulf of St. Lawrence and in the estuary east of the Saguenay River. The term was proposed by Elson (1969) to distinguish it from materials in the Mer de Laflamme which occupied the Saguenay valley, and the Champlain Sea in the St. Lawrence Lowlands. It differs from the Champlain Sea in that marine conditions have continued up to the present day.

The configuration of the Goldthwait Sea at its maximum extent is indicated on Figure 6-3. The inland extent was established by air photo interpretation and determined as the point where kettle holes and irregular terrace topography were replaced by terraces with smooth surfaces or beach ridges. Preglacial valleys were drowned and arms of the sea extended as much as 80 km inland.

The marine limit is highest near Sept-Iles, where it is at 130 m ASL. The altitude decreases toward the south and west: it is 120 m in the Rivière Pentecôte area and 100 m near Godbout. The marine limit is marked by raised deltas and sets of beach ridges near major rivers but over extensive areas it is unmarked because the upper limit of beach deposits is separated from till by a steep bedrock scarp.

No altimetric readings were taken along the flooded preglacial valleys which extend far inland, but by comparing air photo marine limit observations with NTS maps it appears that the marine limit increases in a north-northwesterly direction.

The time transgressive nature of the marine limit of the Goldthwait Sea should be pointed out. The logic of the situation, and radiocarbon data presented in Figure 4-21 suggest that deglaciation and the marine incursion was earliest along the Godbout part of the coast. The date of 8280 (GSC-1856) at Rivière Pentecôte at 40 m ASL, compared to a date of 7580 (GSC-1809) representing a sea level stand at 72 m (i.e. a higher level) near Lac des Rapides, indicates that rebound and emergence were more advanced in the southern coastal area than in the more northeasterly portion of the field area.

Style of sedimentation

Sedimentation into the Goldthwait Sea was very rapid in the first 2000 years after deglaciation, due partly to large quantities of sediment laden meltwater which flowed down the valleys, and partly to continual downcutting and reworking of the sediments, associated with uplift and a dropping base level. An abundance of fine sand and rock flour were carried beyond the melt-water channels into the marine environment so that substantial volumes of sand were deposited as delta foresets at the mouths of valleys where transporting river currents were slowed by the inertial mass of the sea. In some areas sedimentation was fast enough to prevent sand grains from arriving at stable positions or packing arrangements, producing metastable structures and low sediment densities. Turbidity currents also operated in these estuarine environments as indicated by lobate structures within the foreset beds. In deeper water, but where river currents or seasonal changes in regime were still operating, banded clays were deposited. In open water beyond the estuaries the fine sediment, deposited continuously, has massive structure.

Although at least for much of the area there was free circulation of sea water, fossil marine molluscs are apparently not abundant. This could indicate that the influx of fresh water was sufficient in estuaries to limit the spread of salt water species. It is also possible, however, that the scarcity of molluscs is related to the absence of carbonate in the water: i.e. they never existed or were not preserved in this environment.

Emergence

Since deglaciation, isostatic rebound has exceeded sea level rise, so that emergence of the land has been continuous. Borehole data and visible stratigraphic evidence at exposures support this statement by indicating a continuous offlap sequence of sedimentation: as sea level lowered relative to the land, deepwater clays were overlain by nearshore and estuarine sands, which in turn were reworked and became covered by beach deposits.

Near the marine limit there are limited occurrences of reworked till, principally along the flanks of the Baie Trinité moraines and over the upland between Rivière des Rapides and Rivière Ste-Marguerite.

South of Lac Daigle a series of prograding beach ridges have formed along the scarp face. These ridges imply that sea level was falling steadily at the time. Grain size data from individual ridges show that they fine and splay from west to east (Dredge, 1971); thus, during their formation longshore drift was probably easterly in the Sept-Iles area.

As emergence proceeded, wave activity reworked the former deltaic deposits. Because they represent a large supply of unconsolidated sediment, well-defined terraces and beach ridges were cut into or built upon the exposed delta surfaces and valley fill in the estuaries. Longshore currents transported and redeposited sediment until the major terraces coalesced; a blanket of sand covered almost all of the finer marine deposits along the coast, producing an almost flat, but terraced sandy coastal plain. One of the major features resulting from longshore transport is the complex recurved spit which comprises the Sept-Iles townsite (see Figure 4-14). During its formation, currents transported material west from the Moisie delta, constituting a current reversal from the higher prograding ridge sequence to the north.

Local topography and the configuration of the embayment, and variation in wind and wave energy appear to have greatly influenced the formation of terraces which were cut into the delta surfaces, and their elevations; for instance, on the west side of the extensive Ste-Marguerite delta the elevation of continuous beach strands declines to the southwest, tangential to the surrounding bedrock escarpment. It is therefore difficult to relate these terraces to sea level stands. Furthermore, the major terrace sequences on one delta do not correspond well with the sequence on even adjacent independent deltas. As a result, correlation of terrace levels and isobase construction cannot be carried out until chronologically controlled emergence curves have been constructed.

As regression proceeded along the open coast, the sea also retreated from estuaries, so that freshwater streams incised and terraced valley fill marine deposits. In the Moisie area the river eroded laterally eastwards creating an extensive prograding meander scroll belt and a corresponding sequence of river terraces near its present mouth. At Rivière Ste - Marguerite and Rivière Pentecôte streams incised (presently raised) meanders into the delta surfaces (see accompanying map).

Modification of the main landscape units

The evolution of the main elements in the landscape has been described above, but several other factors have modified land form as well: aeolian activity, development of bogs, and mass movement.

Upon emergence, wave-worked deltas were locally modified by strong winds from the east, but aeolian development is restricted to areas around Sept-Iles and Baie-Trinité which are above the 50 metre terrace level. From this I conclude that vegetation had sufficiently colonized the delta surfaces, by the time the sea was at this level, to prevent large scale deflation. The oldest date from organic deposits is 6960 ± 300 (GSC-1811; Mott, 1976), on basal gyttja from a small pond near the marine limit at Walker Lake; and calculations based on a theoretical emergence curve indicate that sea level had lowered to 50 m at Sept-Iles at about that time.

The principal remaining factors in the landscape have been continued alluvial and coastal accretion, the accumulation of peat on flat terrace surfaces (described previously), and the development of landslides. The slides are described in detail in Chapter Seven.

6.4 Possible Relationships to Quaternary Events and Materials Beyond the North Shore

Glacial correlations

Some relationships between Quaternary events along the North Shore and those of surrounding areas are offered in this section. However, direct correlation of materials and events cannot be made at the present time due to the absence of comparable studies in adjacent areas and the lack of chronological control. Because of differences in environment of deposition, provenance, or parent materials, and the long distances involved, glacial deposits of the North Shore can only be correlated loosely with deposits in other parts of the Gulf, Labrador, or the St. Lawrence Lowlands. Chronological controls for both glacial and marine events are based on two radiocarbon dates on postglacial marine molluscs from sites at elevations near, but below, marine limit, and from gyttja from two bogs on glacial outwash gravel. The conjectured correlation of events, which is summarized in Figure 6-4, is therefore based primarily on stratigraphic or relative chronology, placed into the regional context.

1. On the basis of the stratigraphy of other areas, the till is thought to represent the time span covering at least the mid and late Wisconsinan, as shown in Figure 6-4. In this case the till is comparable to the Gentilly Till Gadd (1971), although the texture and mineralogy of the two differ because of differences in parent rock types.

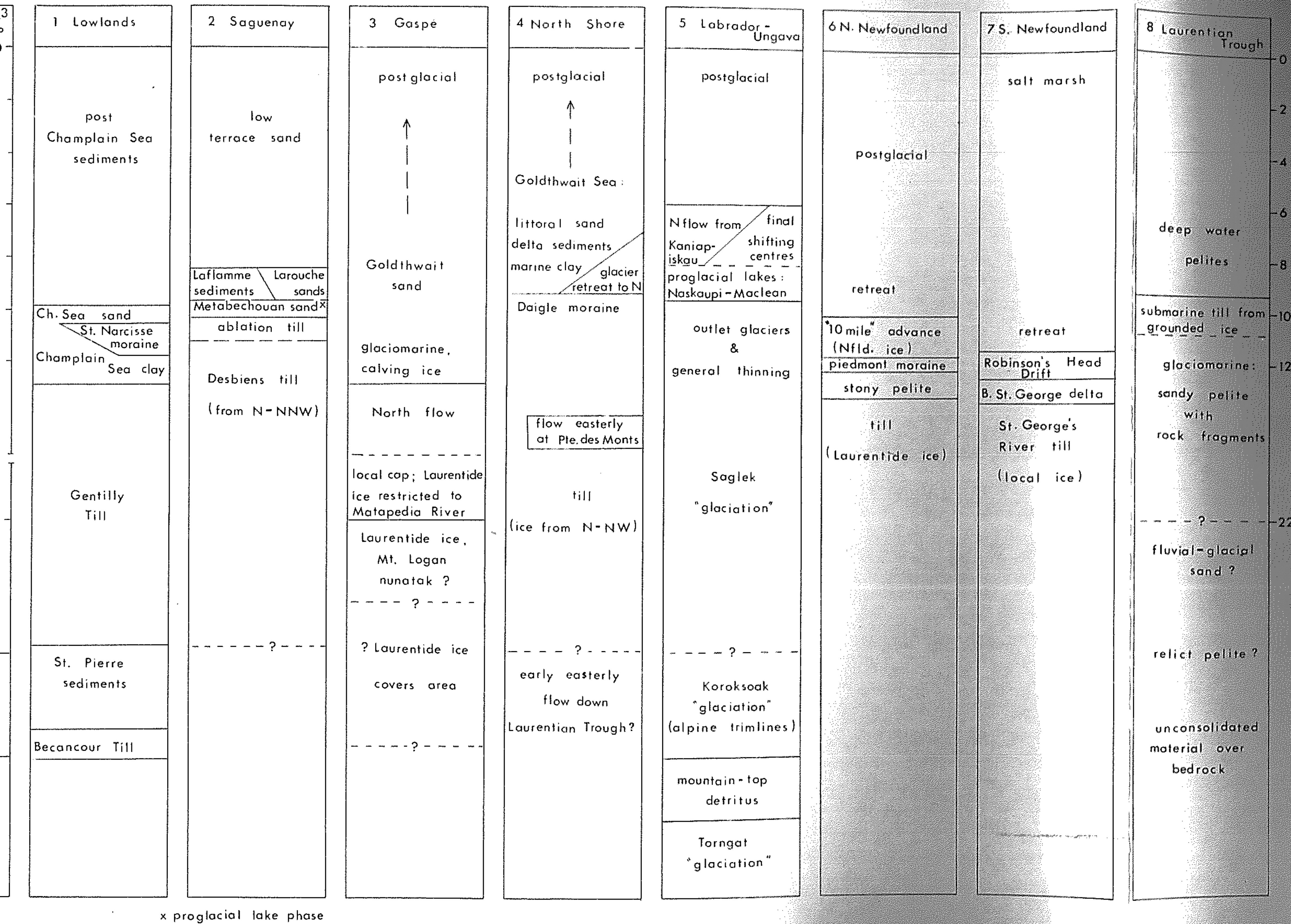


Figure 6-4

Tentative correlation of events on the North Shore with other parts of eastern Canada

References & Sources

1 Gadd, 1976
2 LaSalle, 1966; 1972
3 Lebuis and David, 1972; Lebuis, 1974
4 this report
5 Hughes, 1964; Ives, 1960
6 Grant, 1969b; 1975
7 Grant, 1975; Brookes, 1974
8 Loring, 1975

On the basis that there is a single till sheet and no evidence of warm intervals prior to final deglaciation, the till could even represent the product of the entire Wisconsin glaciation. So far there is no evidence of an early Wisconsin interstadial, which is represented by the St. Pierre and Missawippi beds in the St. Lawrence Lowlands, and by mountain top detritus or trimlines in northern Labrador (Andrews, 1963). There is also no evidence of the late Wisconsin fluctuations experienced in Gaspé (Lebuis, 1973), Newfoundland (Grant, 1975) and the eastern part of the Gulf (Loring, 1975).

The North Shore till has similar textural and geotechnical properties to the lower (basal) component of the till over Labrador-Ungava described by Henderson (1959), Hughes (1964), Kirby (1961) and Eden (1976). The North Shore till is a continuation of the Labrador till, which extends over the northern part of the field area, under the marine deposits (as observed in the stratigraphic section at Lac des Rapides, at the Arnaud Railroad and from borehole reports from the Sept-Iles townsite), and presumably out into the St. Lawrence estuary to the edge of the North Shore and Anticosti shelves. Similar grey sandy till with Laurentian mineralogy covers the northern part of the Gulf shelf and Laurentian trough (Loring and Nota, 1969). Till to the south of the trough and east of the Esquiman Channel has an Appalachian provenance. Nota and Loring (1964) and Loring and Nota (1973) further indicate that the till was deposited subglacially and terrestrially by grounded ice which scoured the trough. The till deposits therefore probably represent the same major glacial event which is recorded on the North Shore.

2. The projected date for deglaciation of the Sept-Iles area is about 9300 BP. Although it compares reasonably well with a date of 9280 (GSC-1965; Lowdon and Blake, 1973) from marine shells near the marine limit at Baie Comeau, only 10 km west of the field area, and with the dates from the Saguenay area, this date is difficult to reconcile with other dates around the Gulf and South Shore,

in which marine overlap apparently occurred between 12,000 and 13,000 years ago (geographic distribution of ages is indicated on Figure 6-5).

There are two interrelated causes for this apparent discrepancy.

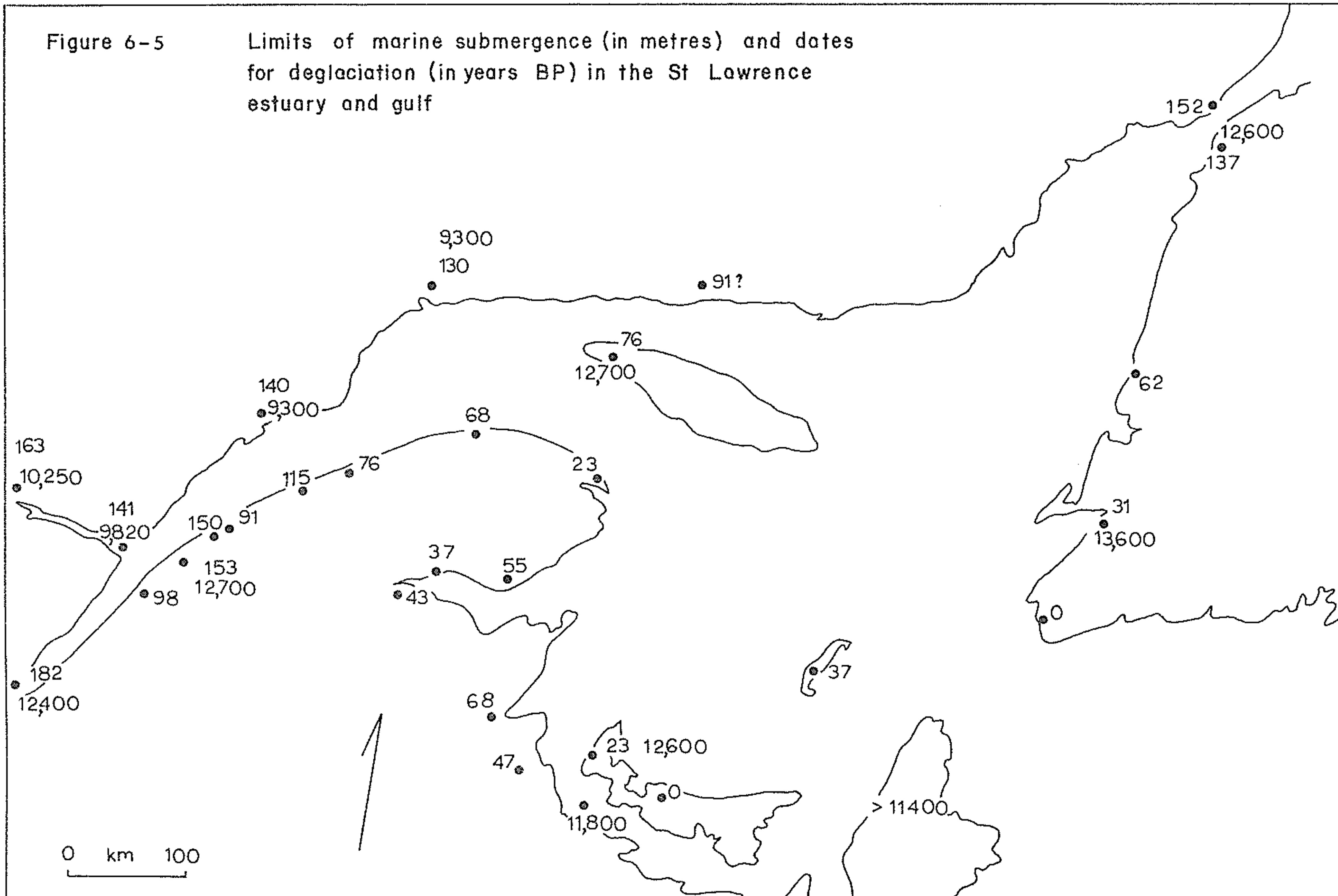
a) Gaspé and the Maritimes were supposedly covered by independent ice sheets during the Late Wisconsinan (Grant and Prest, 1975). It can therefore be argued that the timing and style of deglaciation should be somewhat different from the Laurentide ice sheet, which extended grounded off the North Shore when ice sheets along other coasts were rapidly calving into the sea.

b) Secondly, although most dates indicate a general break-up of the ice between 13,500 and 12,500 BP, ice readvances have occurred in peripheral areas since that time; for example, Lebuis (1972) and Lebuis and David (1972) report a later readvance and rapid calving in the Cap Chat and Tourelle areas of the Gaspé, and Grant (1975) describes a number of readvances as late as 10,500 BP in Cape Breton Island and Newfoundland. The final cessation of glacial activity all around the Gulf may therefore have occurred substantially later than 13,500 years ago. This final retreat of the ice may correlate better with the North Shore chronology than the general break-up of ice in the Gulf, and may represent a widespread regional climatic change.

Figure 6-5 also indicates that the height of the marine limit is less than areas in the St. Lawrence Lowlands, where marine strandlines are found up to elevations of almost 200 metres. The simplest explanation for this is that the highest marine levels were against the ice front and therefore were not recorded.

A second possibility, however, is that the marine limit at Sept-Iles was in fact not ice front bounded. In this case, the implication of the relatively low value of isostatic rebound is that the ice was relatively thin over this area; i.e. this area was near the eastern edge of the Laurentide ice sheet. A corollary of this theory is that the ice which reached the continental shelf

Figure 6-5 Limits of marine submergence (in metres) and dates for deglaciation (in years BP) in the St Lawrence estuary and gulf



and which is shown by Figure 18-5 in Flint (1971) is either not Laurentide ice or else not late Wisconsin in age.

The timing of break-up of the glacier in and directly south of the field area is important, but unresolved. Conflicting ages for dates on the Champlain Sea, based on work in the Great Lakes and marine dates in the Lowlands, demand an examination of the timing of possible marine influxes from the Gulf of St. Lawrence. The concept of glacial break-up in the Gulf supports the oldest dates for the Champlain Sea, while the limited absolute chronology from the North Shore suggests a much younger age for deglaciation and marine incursions.

3. Since the Gaspé, Maritime region, and most of Newfoundland had separate ice sheets at least for the late Wisconsin (Grant and Prest, 1975), there is little basis for correlation of moraines there with those deposited during the glacial retreat phases of the North Shore and Labrador-Ungava; those formed in the St. Lawrence Lowlands, such as St. Narcisse (Parry and MacPherson, 1964; Gadd, 1971), relate to the same ice sheet, but predate those of the North Shore.

The moraine at Lac Daigle, together with the disconnected morainic remnants which extend westward over the map-area to Lac Dionne appear to join with the moraines mapped by Sauvé and LaSalle (1968) northeast of Manic 2. A minimum date of 9300 BP on the Daigle moraine correlates fairly well with an age of about 9150 at Manic 2.

There are no dates yet available for the minor moraines in the south part of the Cap Chat area, and no apparent analogous or correlative deposits in adjacent areas. A "blip" on the seismic profile S-62#5 in the offshore area south of Sept-Iles (Nota and Loring, 1964) could possibly be an underwater extension of these moraines although this apparent ridge of coarse grained material is not present on the other profile lines.

Postglacial correlatives: pollen profiles

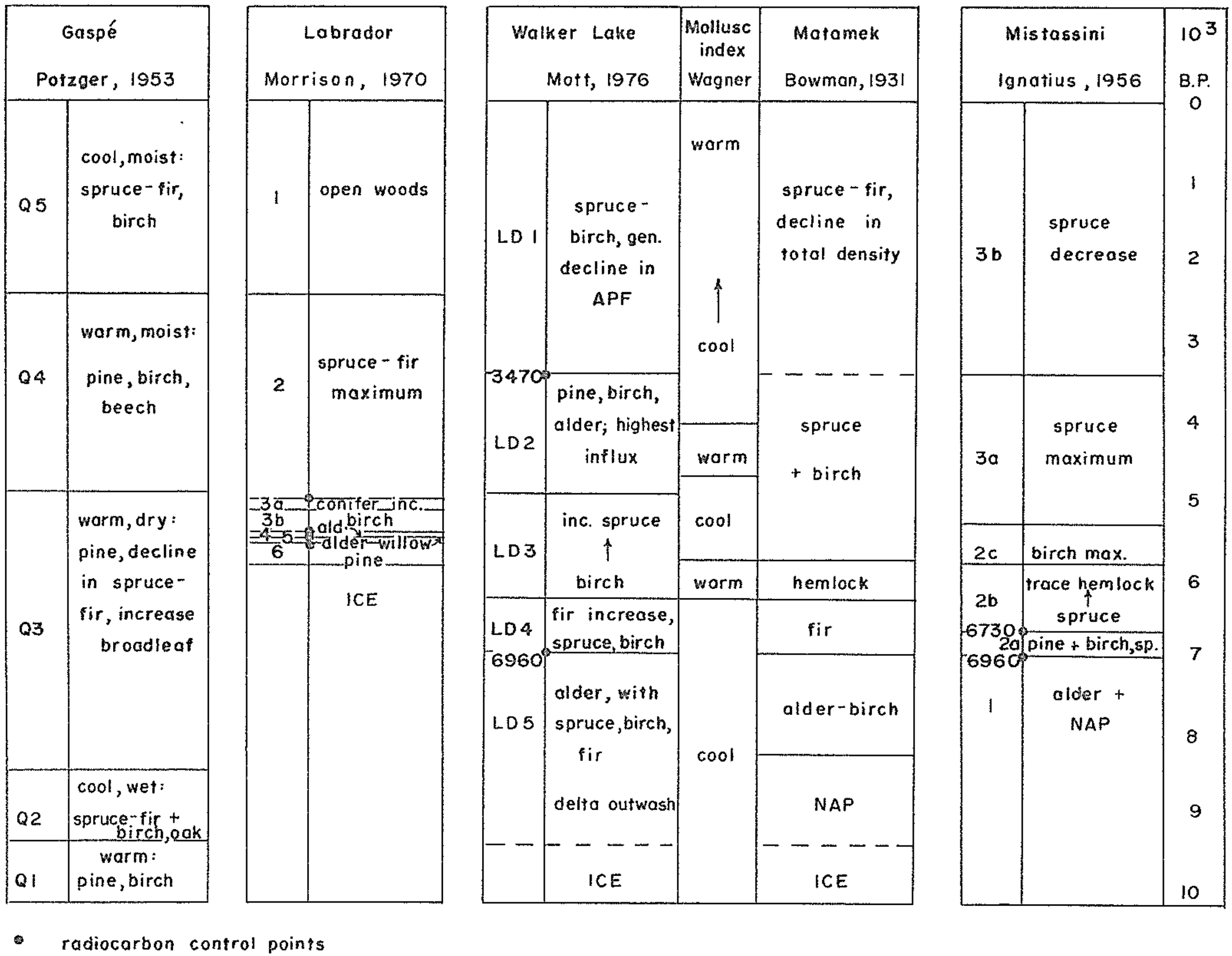
Postglacial conditions along the North Shore can be determined by interpreting pollen diagrams. Within the field area, the pond and bog cores analysed by Mott (1976) and Bowman (1931) (Figure 6-6) are in basic agreement. Both have lower alder zones reflecting initial local wet soil conditions. The succeeding zones indicate the establishment of a coniferous forest culminating in a spruce-fir-birch assemblage which Mott claims represents "better growing conditions". This zone is followed by a decline in absolute pollen influx interpreted as a "deterioration in growing conditions".

There are two major differences in the two profiles: (1) Bowman's data shows a basal NAP zone while Mott's does not. Based on studies of bogs in southern Quebec, Auer (1930) has attributed this zone to the emergence and drying out of the bog surface. Even though Mott's profile is taken from a pond in outwash rather than a bog, the absence of this zone is unexpected because coring extended into the underlying mineral horizon. The relatively young date of 6960 from the bottom of the core suggests that the basal part is either missing or not preserved.

(2) Bowman's data also shows a *Tsuga* peak which is not present in Mott's profile. The occurrence of this horizon is fairly important because the *Tsuga* influx forms the basis of Terasmae's correlation of this unit to Potzger's Q4 zone, when hemlock migrated into the Gaspé area.

The molluscan assemblages plotted on Wagner's diagram (Figure 4-23) provide a means of estimating thermal conditions in postglacial time when her data is converted from "elevation" to "time" by interpolating between dated sites. The results show that warm periods occurred between about 4200 and 4700 BP, and between 5800 and 6300 BP. These dates correspond surprisingly well with the pollen data. The middle warming corresponds to the time of the

Figure 6-6 Postglacial correlation chart for the pollen record



Tsuga occurrence in Bowman's profile, while the upper warm interval falls within Mott's zone 2, which has been associated with growing conditions that were better than the present.

The pollen profile of Mott together with Bowman's data provide a means of correlation by relating the climatic sequence on the North Shore with profiles obtained from other parts of Quebec. Results from the field area can be readily extended to the Mistassini-Chibougamau area, which had similar deglacial chronology and has similar vegetation today. The pollen zones established by Ignatius (1956) show the same sequence of vegetation types except that his lower pine zone (2a) is not represented along the North Shore. The timing of the transition from alder to conifer forest is very close to the transition in the Walker Lake area as shown by Mott (1976).

An attempt to correlate the North Shore profiles to work in the Gaspé and central Labrador-Ungava is also indicated in Figure 6-6. The correlation along this longitudinal traverse is inexact because:

1. the early zones which reflect conditions of deglaciation and the establishment of vegetation are time transgressive, and
2. the sites are in different climatic-biotic regions and therefore have differing vegetation species associations.

Morrison has already tentatively correlated his zones to Potzger's climatic units (although the species are very different), and the correlation with the North Shore profiles presented here is based on an interpolation between these two records.

Morrison claims that his pine zone relates to a pollen influx which occurred during warm, moist conditions elsewhere, and he correlates this occurrence with Potzger's Q3. This zone may also correlate with the _Tsuga_ zone of Bowman's profiles and hence the lower part of zone LD3 of Mott. Zone 3 of Morrison is probably comparable to Mott's LD3, where birch and spruce are increasing.

The maxima of zone 2 of both authors reflect better than usual growing conditions and as such, correlate with Q4 of Potzger, which is his warm, moist period. All profiles have an upper horizon in which there is a decline in species abundance and which could represent the cooler, wetter climate of Potzger's Q5.

In this interpretation, the *Tsuga* zone in Bowman's profile corresponds to Potzger's Q3 and the earlier warming trend in Wagner's curve, rather than to the Q4 unit as indicated by Terasmae (1969).

7 ECONOMIC GEOLOGY: APPLIED QUATERNARY GEOMORPHOLOGY

When mapping of the area was first undertaken, the surficial deposits known to be of economic interest were the titaniferous sands at Moisie (Dulieux, 1912) and small quantities of ochrous clays located in isolated pockets along the coast (Faessler, 1942a). Emphasis has shifted considerably since that time, for the materials of economic importance are those which affect settlement, construction, and economic development. Sources of aggregate, foundation substrate characteristics, water supply factors and natural hazards are of primary consideration today.

This section summarizes material presented in the preceding sections which relates to environmental engineering; the subsections on water balance and landslides contain some new information.

7.1 Extractive Resources

Sources of aggregate

Glacio-fluvial deposits provide a good source of gravelly material for roadbuilding and townsites. The aggregate consists of Precambrian igneous and metamorphic rocks; there are no carbonates or chert, very small amounts of schist, and the material is generally free of fines. The best source of loose aggregate is map unit 3. Those deposits which are presently accessible are associated with unit 3c: they are the outwash fans at Lac Pentecôte, Rivière Vachon, Rivière aux Rochers, and the outwash plain south of Lac Daigle. The Daigle outwash plain, the largest of these, is the only one being commercially exploited at present. More remote sources of large amounts of coarse aggregate are located in buried valleys (such as the Ruisseau Daigle Valley north of Sept-Iles, and another located 6 km west of Godbout) and in former outwash channels. In the major river valleys, grading characteristics of the aggregate are highly variable, but generally the coarser material is on the higher outwash terraces. Low terrace alluvium provides finer, shallower gravel resources.

Sand is also used for construction purposes. Deep deposits of well-sorted (uniform) sands are widespread, since they are the principal component of the extensive terraces along the coast (map unit 6) and lower parts of the large rivers. Because of its widespread distribution along the coastal development-corridor, sand has been extracted from shallow borrow pits wherever it is required.

Till can be used as a secondary source of sand and gravel, but deposits are generally shallow and large boulders may make extraction and treatment (crushing and screening) difficult.

Two rock quarries near Lac des Rapides supply rock-block aggregate. Crushed anorthosite is used for shore protection (rip rap) between Sept-Iles and Moisie, and for roadbed ballast along the railways.

Peat mining

Extensive peat deposits overlie the sands on the coastal plain between Rivière Pentecôte and Moisie. These deposits cover a total area of about 15 000 hectares, and extend to a depth of about 4 metres. The only peat extraction operation in the area is situated on the periphery of a string bog near the townsite of Sept-Iles. The peat is used locally for landscaping.

7.2 Water Balance

Two aspects of water balance are very closely related to the nature and distribution of unconsolidated deposits: sources of municipal and industrial water; and the possibility of irreversible accelerated soil erosion caused by alteration of the existing water balance.

Groundwater availability

The availability of water in aquifers is important for planning consumptive use, especially since the rivers and lakes which are presently used as reservoirs are shared by different economic sectors (particularly forestry industries). The St. Lawrence in this area is saline and therefore cannot be used as a fresh water supply.

The groundwater report for Sept-Iles (Iron Ore Company report 8717, 1970), states that in the uplands, bedrock fissures do not provide a significant amount of water. The sandy till is capable of storing small quantities, but its shallowness and lack of continuity greatly restrict its usefulness. Buried valleys and partially filled outwash channels are probably reasonably good aquifers, but most are too far inland to be of use in the near future. Therefore, for present levels of consumption, the coastal sand plain provides the most efficient reservoir of ground water. The sands are medium-grained, well sorted, and very extensive. They are underlain at depths of from three to sixty metres by less permeable silts and clays, or bedrock.

Water is derived from infiltrating precipitation falling directly on the sand plain. Only very small amounts enter this reservoir either by runoff or by infiltration around streams. (I.O.C. report, 1970). Water availability, therefore, is directly related to the seasonal climatic water balance.

The seasonal water balance has been determined using the Thornthwaite-Mather equations which relate the seasonal march of precipitation to runoff, evaporation and soil moisture. Evapotranspiration and storage capacity values have been corrected for latitude, soil type, and vegetative cover. From the water balance plotted as Figure 7-1, several conclusions about water availability can be drawn: (1) There is no period of soil drought. During the summer months there is a slight amount (3.8 cm) of soil moisture used in evapotranspiration but this is much less than the field capacity. For the remainder of the year, from September until May, there is a water surplus, which is greatest in the spring and fall. (2) The absence of streams on the coastal plain, the permeability of the sands, and the rapid drying observed in the field after rain suggest that much of the potential run-off in the equation (i.e. the water surplus) actually infiltrates. (3) Out of a total annual precipitation of 110 cm, 46 cm is presently lost through evapotranspiration, and 61 cm is available for storage or use without permanently depleting the aquifers. For much of the year, however, part of this moisture is stored on the ground as snow, so that under the worst conditions, only 12 cm can be pumped without creating conditions of moisture stress in the soil.

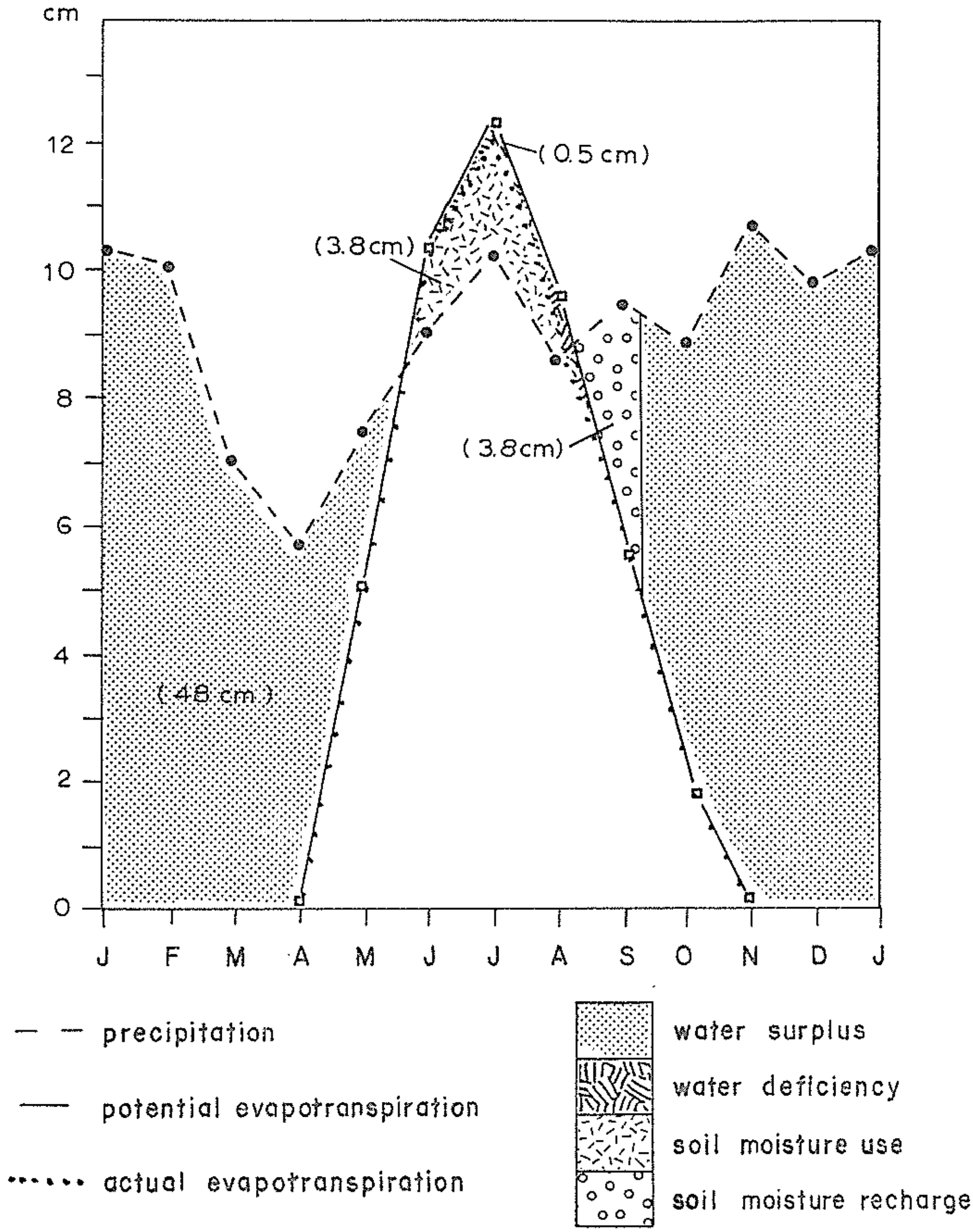
Summer pumping tests (I.O.C., 1970) indicate that the aquifer between Sept-Iles and Moisie has a maximum transmissibility of up to 65 000 g.p.d. (The permeability of the sand is 600 gpd/ft^2). The water is good quality. Total dissolved solids are 43 ppm. The principal ions are bicarbonate (12 ppm), sulphate (4 ppm), sodium (3 ppm) and calcium (2.5 ppm). There is no free iron and less than 0.18 ppm dissolved iron listed in the water quality data which date back to 1956 (Canada Mines and Technical Surveys, 1962). (Despite this the water used by most communities is usually a rusty orange colour.) The pH of the water is 6.2.

Runoff and soil erosion

Because most of the Quaternary deposits are noncohesive they are prone

Figure 7-1 Water balance at Sept Iles

(based on the Thornthwaite-Mather model)



to rapid subaerial erosion under certain conditions. Normally, the vegetative cover protects the soil from violent fluvial erosion by chemically binding particles to the roots and by anchoring the soil mass. But when vegetation is removed, the soil is no longer protected.

The accompanying graph (Figure 7-2) shows present run-off-precipitation relationships in a large drainage basin (Moisie), and a small basin (Rivière des Rapides). These were calculated from discharge records from the Moisie and Rapides Rivers. The hypothetical run-off that would occur if the vegetation were removed by clearcutting is also calculated from published climatic data. Vegetation removal changes the run-off curve in several ways:

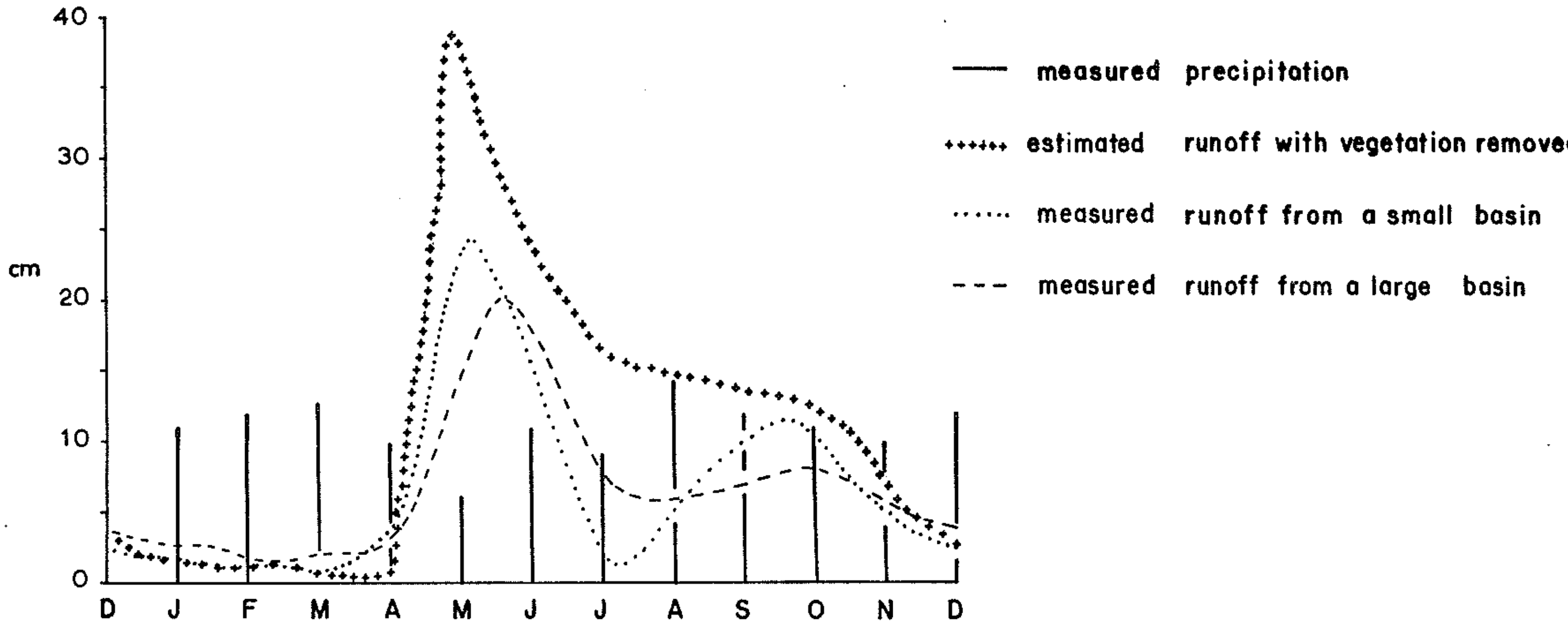
1. The total amount of run-off increases by 48 cm because there is no evapotranspiration.

2. The snowmelt duration is concentrated into a period of about 25 days.

3. At its peak, snowmelt run-off is 60% to 100% higher than the run-off in vegetated basins.

One effect of the concentrated increased run-off is the production of turbulent overland flow. With turbulent flow conditions, unprotected sand-sized particles are entrained and carried into streams as suspended load. The result of uncontrolled removal of vegetation in the uplands is therefore accelerated erosion whenever overburden is not deep enough or permeable enough to let excess water infiltrate. Field observations confirm that accelerated erosion has already occurred in the places where vegetation has been burnt off. The burnt-over area northwest of Clarke City is completely bare of overburden, although nearby vegetated areas are covered with till. It is interesting to note that H.Y. Hind (1864) has described more dramatic results of vegetation removal which occurred as a result of the "great conflagrations of 1785 and 1814". He claims that the subsequent subaerial

Figure 7-2 Precipitation - runoff relationships, Sept-Iles region



erosion has removed sand and fines, leaving only "chaotic masses of erratics on the (Labrador) plateau, which were piled up to three feet thick, with nothing in the interstices".

Accelerated erosion due to channelled flow occurs along lumber roads. On the uplands, virtually all the "secondary roads" on the topographic map are completely washed out as a result of micro gullying caused by the channelling of water into ruts (cf Figure 7-3). Channellized flow may also have been partially responsible for the catastrophic gullying which occurred in the coastal deltaic sands (discussed below).

Increased peak river discharges associated with vegetation removal may cause undercutting and river bank erosion, particularly on the coastal plain where large rivers cut through thick estuarine sands. One catastrophic occurrence of undercutting caused subsequent siltation of the river channel and harbour at Rivière Pentecôte (Figure 7-4).

7.3 Landslide Inventory

Introduction

Both inactive and active landslides are encountered in the field area. These slides presently have the form of cones, gullies, hummocky slumps and pear-shaped flows. Most of the inactive slides are of the flow variety. The distribution of slides is economically important since they occur along the coastal plain where settlements, transportation and communication routes are concentrated (Figure 7-5). An inventory of the slides themselves (Table 7-1) is presented in the following sections. The inventory provides information relating to areal, morphological and stratigraphical aspects of slides. The descriptions are rather detailed since landslides have not been previously investigated in this, or nearby regions, and because economic

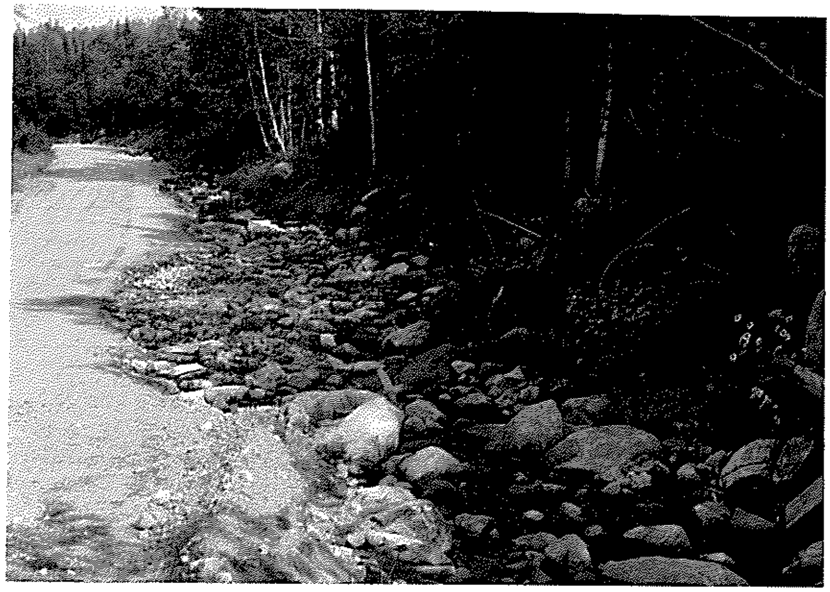


Figure 7-3 Channeling of runoff into ruts on a lumber road north of Baie Trinité. In 1972 the road occupied the right half of the road shown in the photo, and the area which is now part of the creek bed. Photo taken in 1974.

Figure 7-4 Siltation of the harbour area at Rivière Pentecôte.

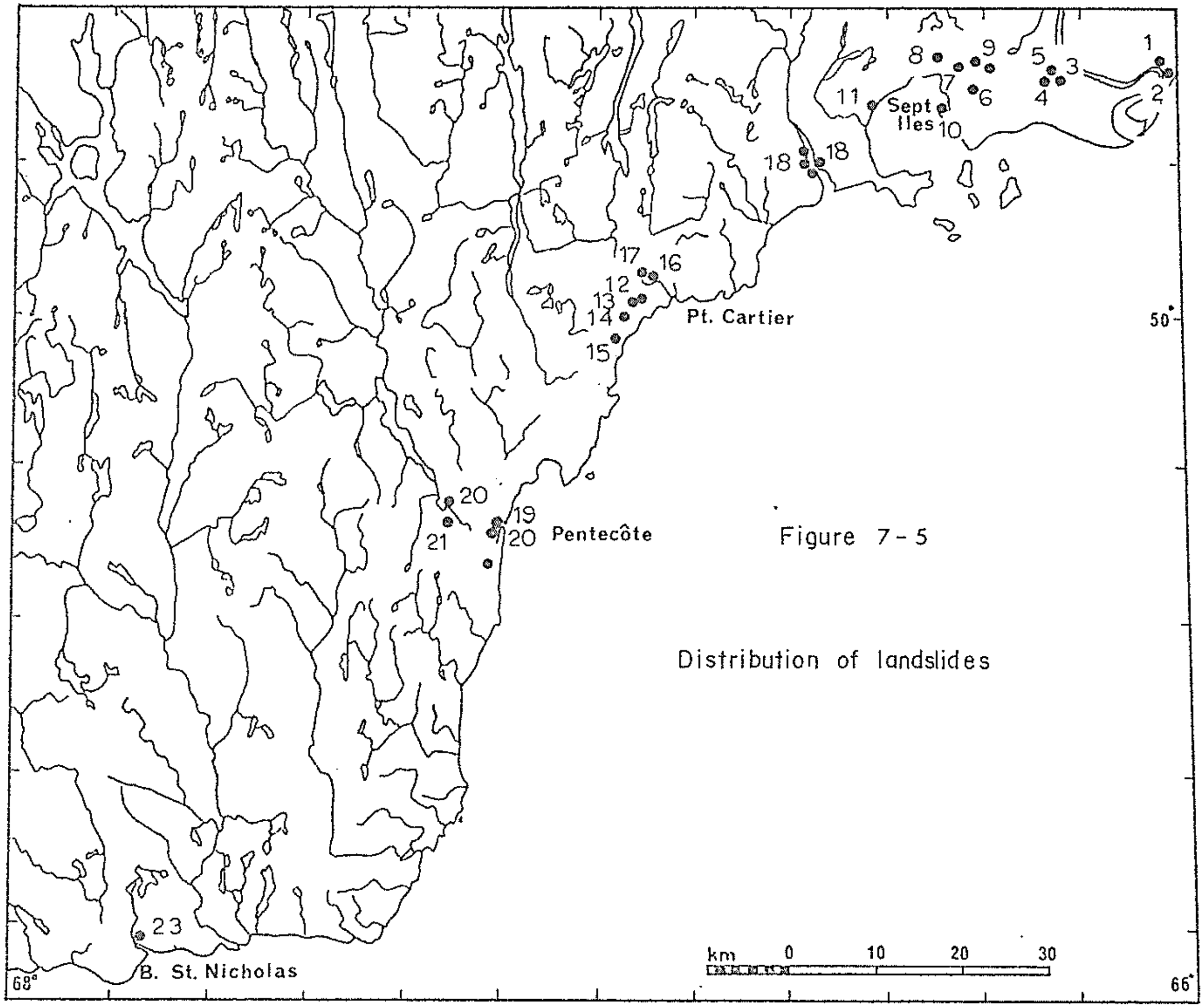


Figure 7-5

Distribution of landslides

Table 7-1 Airphoto summary - Landslide inventory

#	Shape	Dimensions(m)	El.base(m)	El.top(m)	Max. Backslope(°)	Active/ Inact.	Sediment	**(m) Sed. Thickness	Surface Cover
1	gully	*1980x25	0	31	55	A	sand	>30	bare
2	flow	*1440x72	15	31	40	I	sand	>16	trees
3	semi-circ. flow	720x360*	31	61	43	I	silt	>30	trees
4	elong.pear	*3.8kmx1.6km	55	95	34	I	si-clay	>40	trees/part deveg.
5	semi-circ.	irreg	55	--	53	A	si-clay	>27	bare
6	circ.pear	*720x648	43	61	40	I	si-clay	>18	trees
7	converging gullies	*540x25	31	43	55	I	si-clay	>12	bare
8	irreg.	720x540*	31	67	50	I	si-clay	>36	bare
9	scarp (3) crenulations	*144x432	98	137	43	I	sand & silt	>39	trees
10	bowls (4)	*5x7	0	8	55	A	si-clay	100	bare
11	irreg (3) slump blocks	*3x7	0	5	55	A	si-clay	> 5	bare
12	amph.slump	*180x480	45	76	35	I	s or silt	>31	deveg.
13	amph.slump	*250x790	45	76	45	I	sand or silt	>31	trees
14	amph.slump	*144x900	45	76	45	I	sand or silt	>31	trees
15	bowls	1x2*	~30	~45	50	A	si-clay	>15	bare
16	amph.bowls	*250x180	61	75	27	I	s or silt	>14	trees
17	amph.bowls	*215x140	61	82	27	I	s or silt	>21	trees
18	open cones(4)	144x360*max.	15	61	53	A	sand	>60	bare
19	bowl	*4x5	45	55	65	A	sand	>55	bare
20	amph.	*216x288	76	137	53	I	sand & silt	>61	deveg.
21	irreg	420x180*	45	85	42	I	sand	>40	trees
22	cones	*43x43	0	61	38	A	sand	>60	bare
23	bowl	*3x4	7	12	50	A	si-clay	> 6	bare

* axis orthogonal to river or bluff
** determined from heights of back- and sidewalls

development is proceeding at a rapid rate, generally without regard to terrain conditions.

Landslides in sand

Minor riverine forms

1. Small conical scars exist along the lower reaches of Rivière Pentecôte where the river has eroded 60 m bluffs into grey silty sands which fill the preglacial valley (locality 19-21 of Figure 7-5). Similar forms, with basal fans, are also found along the right bank of the lower Ste-Marguerite River (locality 18). Here, about 10 m of horizontally-bedded beach sands overlie 25 m of southward-dipping soft grey sand, which in turn truncates 25 m of horizontally-bedded grey clay. Oversteepening and basal sapping are probably important factors causing failure. The size and number of these features has increased since the aerial photos were taken in 1966, and since erosion of the bluff is proceeding at a rate which is faster than the Ste-Marguerite River can remove the material at the base, shoals are developing along the river margins.

The slides are significant in terms of the amount of sediment involved, since the bluffs are about 60 m high. A slump can cause a diversion of the river, thereby promoting lateral migration and further bank failure.

2. A small flow slide in the fine micaceous sands which comprise the banks of Rivière Pentecôte occurred while the writer was standing on the slope. Although very small (4 m x 5 m; locality 19), this slide partially documents the failure process: Because of the disturbance caused by standing in a small irregularity on the slope, and by disturbing the metastable primary sedimentary structure during the extraction of shells, water began to seep out of the face of the bluff, and at the same time, the "backwall" and

bottom of the depression began to disintegrate into one-to-two-centimetre-sized fragments. These fragments rapidly lost their form and flowed out the bottom of the bowl in a slurry. The velocity of the flow was about seven centimetres per second in the depression (the area of least slope). Disturbance of the slope evidently caused liquefaction of the sands, which have a high void ratio because of rapid primary sedimentation and high water content because of the underlying clayey layer of less permeable material (see Figure 7-6). The northerly flank of the depression, which had no vegetation, completely collapsed during failure, but the southerly spur, which was vegetated, remained intact.

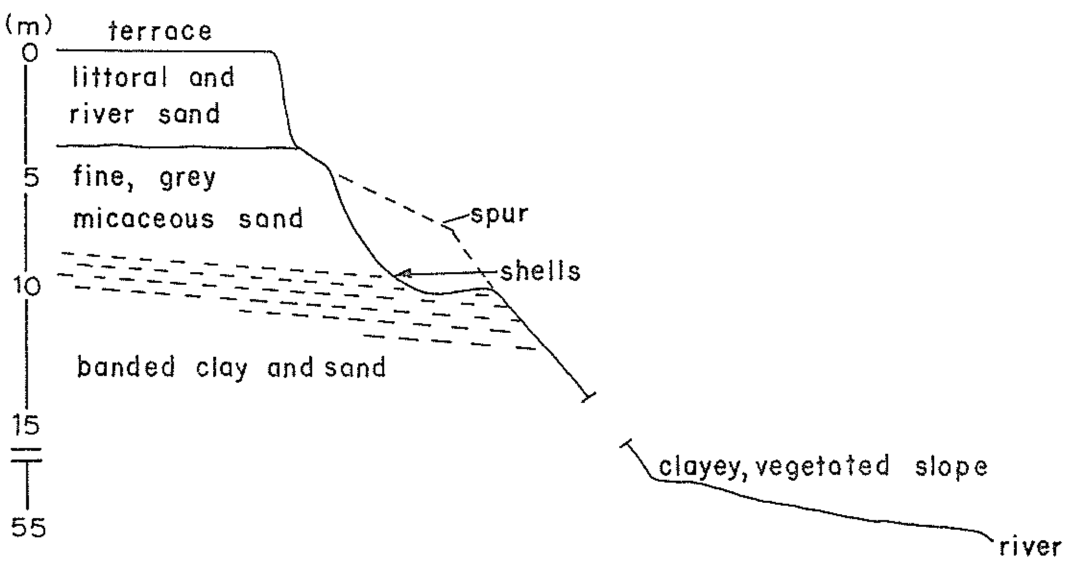
The gully-flow

The term "gully-flow" refers to a peculiar type of catastrophic event which occurred on the left meander bank in the Moisie River (location 1, 2). The land surface in this area is a flat marine terrace at about 30 m above sea level. There are three gullies along the meander bend, and a fossil gully whose base level is perched about 15 m above present sea level. The river bank is 30 m high, with side slopes at 30° to 40°. It is composed of stratified deltaic sand. Within the sand beds are layers of organic material, irregular bedding planes, and zones of fine homogeneous sand. The sands are poorly compacted, and hence the permeability is generally quite high, but variable. The sandy facies is underlain (unconformably) by silty marine clays (see Figure 7-7).

On June 16, 1959 a "hydrant" of muddy water was reported spouting from the side of the bluff in a small vegetated gully.[1] This was followed by flowage of the bank and movement of the trees. The flow lasted about five hours during which time 200 000 cu.m of sediment were moved. The gully

[1]Transcripts of reports relating to the 1959 flow are on file at the offices of Iron Ore Company of Canada, Sept-Iles.

Figure 7-6 Stratigraphy at Rivière Pentecôte



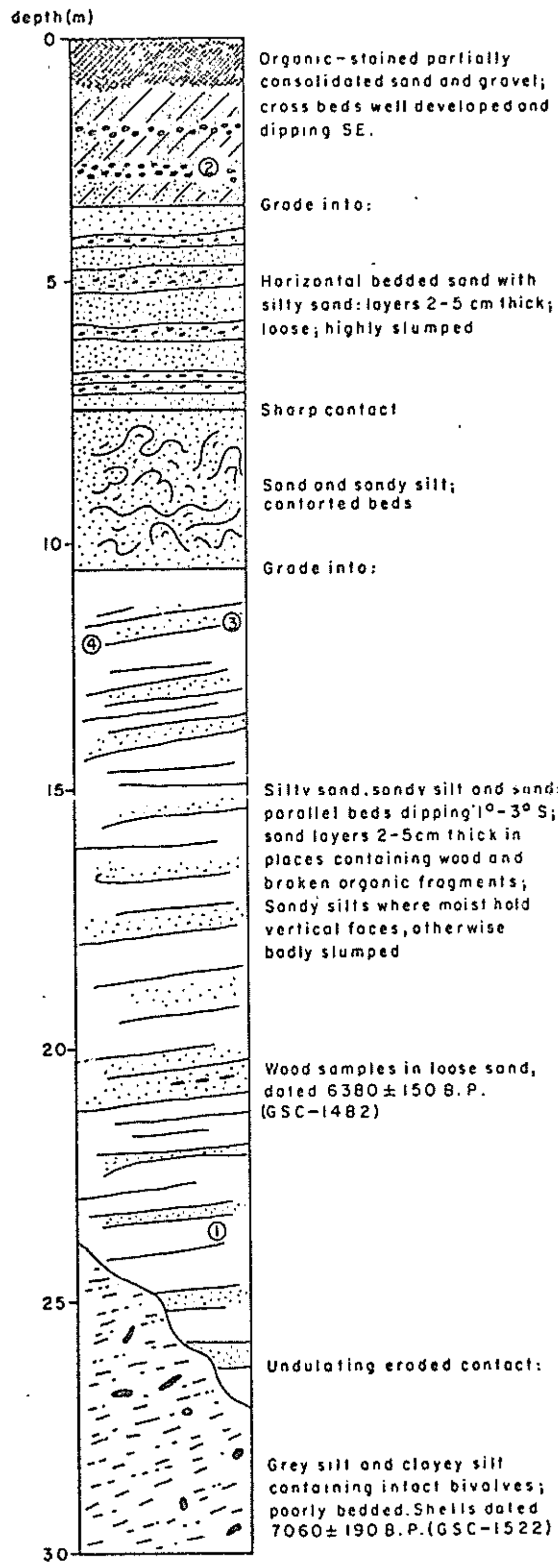


Fig. 7-7. Stratigraphy at the gully-flow, MoisieRiver.

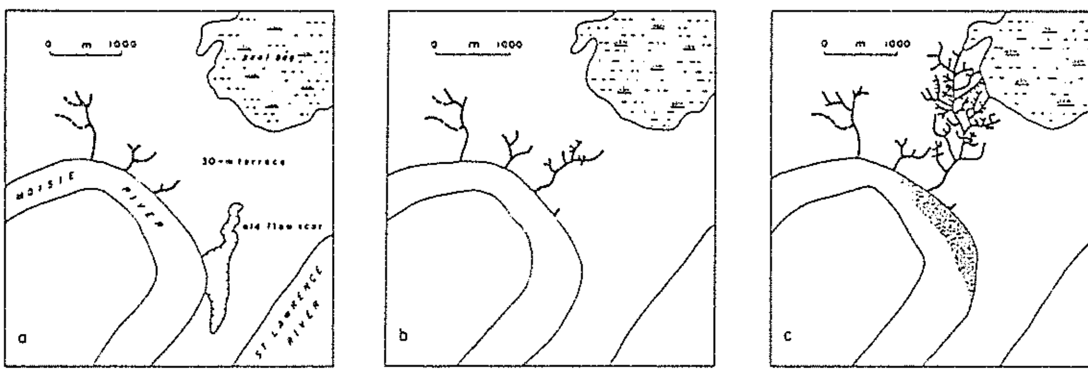


Figure 7–8 Development of the gully system. (a) The three small wooded gullies that existed in 1953 (from air photo A 13682-277). (b) Gully development after the storm of 16 June 1959 (from air photos Q 65336-82, 83). (c) The gully pattern after the flow of 4 November 1966 (from air photos A 20266-135, 136).

expanded headward and branched into tributaries. No major additional flowage occurred until November 4, 1966, when the same gully system was enlarged and a second gully was initiated upstream. On this occasion, another 3½ million cu m. of sediment flowed out and fanned into the Moisie River channel, temporarily damming the river and subsequently causing flooding of cottages downstream. At present a small stream flows in the bottom of the gully. It has incised a channel through the remnant of the 1966 fan, whose surface stands about 8 m above the present summer channel level. On both occasions, failure was preceeded by excessive rainfall. In 1959, 10.0 cm fell in the two days prior to flow and in 1966 11.4 cm fell on November 3. The permeable sands overlying or within less permeable beds may therefore have become saturated; excessive porewater pressures probably developed, which were partially released as the observed hydrant in the side of the gully, and partially dissipated during liquefaction and subsequent flowage of the soil mass.

The unique morphological appearance of the flow may be the result of a previously existing piping network, although the location of side gullies coincides in part with the grid of lumber tracks on the surface.

Although the same stratigraphic and precipitation conditions existed all along the river, gully-flow development has only occurred in one area. Two possible reasons for failure at this particular location are apparent:

1. The flow occurred in the active slope at the meander. At this time, discharge was twice the normal amount. Erosion by undercutting may have occurred, producing slope instability which, with unstable ground conditions, resulted in total failure.
2. The areas where gully-head erosion occurred correspond to the lumbered areas. The lumbering did not cause the failure since a) the morphological pattern does not correspond completely with the track network.

b) rapid failure and gully development only occurred after excessive rainfall.

But lumbering may have contributed by

a) decreasing interception, thereby increasing the infiltration rate to the point where pore pressures built up too fast

b) accelerating infiltration or concentrating water in the tracks, particularly where they are parallel to the natural flow gradient (i.e. normal to the main river and later to the gully bank). Where tracks intersect an expanding gully, they act as points of erosion for the development of tributary gullies.

c) encouraging headward erosion. Although the gully pattern does not generally follow the track pattern, branching or extensive headward erosion is visible on the air photos where an access track had been built up the gully slope of 1959 and onto the terrace. These seem to be erosion-prone areas. This relationship can be noted by examining the track pattern on the 1965 photos, and comparing it to the area of gullying on the 1967 photos.

The gully-flow here seems to be an unusual form of accelerated erosion. Nevertheless, its occurrence is important. The recurrence of this event over the past 15 years and the presence of a fossil flow nearby indicate that failures will probably recur when local soil conditions are abnormally stressed in the future. These flows are located at the site of the easterly extension of Route 138 (Route 15). Since land use changes, combined with natural stresses, create unstable conditions, the utmost care should be taken to minimize disturbance along this part of the river.

Landslides in clays

1. General occurrence

Landslides have occurred in the silty clays which make up much of the underlying material and some of the surficial deposits of the coastal plain. They are located along the outer edges of flat terraces which range in elevation from sea level to 130 m, but are more prevalent along higher terraces than ones near present sea level. The absence of debris at the base of the bluffs indicates that the landslide debris was carried away by wave and current activity when the bases of the scarps were at sea level or local base level.

In the case of the very old inactive slides, the surfaces are presently vegetated with spruce and fir, but recent slides are covered with moss and scrub growth. On active slopes the bluff is usually bare. For all slides, the bedrock is believed to be far beneath the surface.

Slides are often difficult to recognize from air photos. Along rivers slide areas can be confused with meander scars, especially on small scale photography. Old inactive slides are difficult to see (on the ground as well) because the area is mainly wooded. By traversing the coastal bluffs a number of slides were found that were not observable on the air photographs with scales as large as 1:10,000. The same situation probably exists inland. On the aerial photographs the larger slides can be identified by their concave slope, and sometimes by the presence of terracettes. A number of smaller ones, however, probably went unnoticed.

2. Inactive slides

Most flow slides in the area are inactive; they are concentrated along the major crenulated scarp north of Sept-Iles (localities 3-9) and in the raised clayey terraces between the Rapides and Moisie Rivers.

The QNS&L railway runs along an old pear-shaped flow slide (locality 4) from milepost 8.5 to 11.4 northeast of Sept-Iles. The major and minor axes have dimensions of 3.8 and 1.6 km respectively. The backslope has a present inclination of 34° and the lip of the flow is at the Moisie River at 54 m ASL. Within this fossil flow, failures occurred during the construction of the railway:

> "During the excavation of the tunnel in 1951, a short section of the roof near the south portal collapsed and allowed the overlying sediments to subside. Some 60,000 cubic yards of banded sediments entered the tunnel in fluid condition"
> (Pryer and Woods, 1959, p. 65).

In September 1953 and spring 1954 rotational slips occurred in a cut slope near the tunnel. The first incident followed a heavy rain and failure was attributed to the development of hydrostatic pressure in the discontinuous, permeable sand strata within the banded silty clay. In the second case, a combination of rain and snowmelt raised the water table, which gave rise to local upward artesian conditions in sandy lenses within the clay.

Old slumps exist at Port Cartier along a 30 m bluff which runs parallel to the present coast, about two kilometres inland (locality 12-14). Most of the bluff is covered with spruce-fir forest. In this case, failure occurred by rotational slumping along 2000 m of the bluff (see Figure 7-9, 10). Hydro-Quebec has devegetated the slide area and located pylons on the outer edges of the clay slope and terrace. Devegetation has caused gullying on the adjacent stable parts of the bluff. With the disturbed stratigraphy of the slumped zones, heavy precipitation may produce conditions leading to new instability problems along the right-of-way.

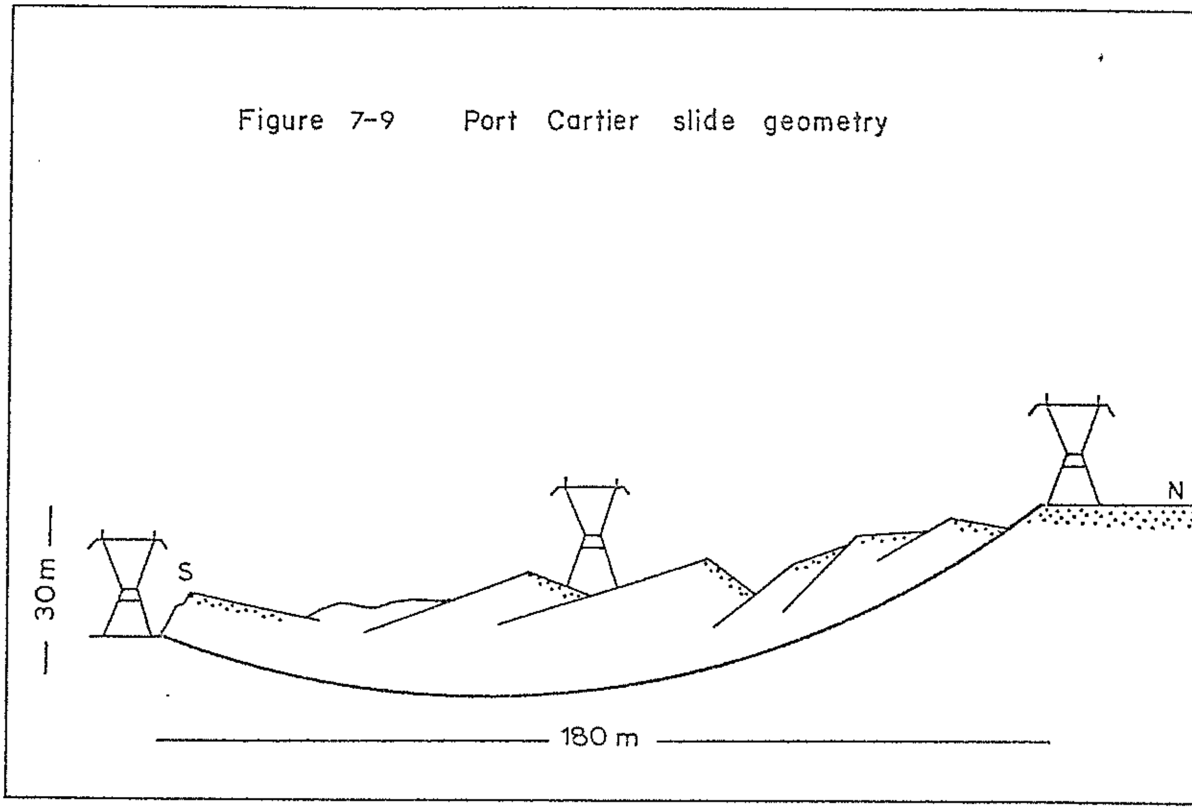


Figure 7-10 The Port Cartier landslide scar. The deforested right-of-way for the Quebec-Labrador power-line clearly shows the backwall and several slump blocks.

3. Active slides

All of the active slides in the field area are very small; their significance lies in the fact that they are occurring only at construction sites or roadcuts, where natural slope or drainage conditions have been altered. The occurrence of these slides shows that small stresses are capable of inducing rapid changes in the landscape.

Multiple slide scars in stiff fissured grey silty clays occurs in the bluffs along Rivière St. Nicholas (locality 23) and along a bluff about 750 m long at the housing development around the Baie des Sept-Iles (locality 11). Along the head of the Baie the bluff is 10 to 15 metres high and consists of about two metres of stratified beach sand which truncates massive grey silty clay. The clay face is very wet at the top but is dry a short distance below; the lower part of the slope is segmented by an integrated network of vertical and horizontal fissures. These fissures are from 20 to 100 cm in length, about 5 cm in open width, and 10 cm in depth. The dry surface of the face of the bluff stands at 50 to 55^{o} and the dry clay has unconfined compressive strengths of $4\frac{1}{2}$ kg/cm^{2}.

Rotational and flow slides have developed along this bluff where drains were laid in the overlying sands. Failures were probably caused in part by excessive pore pressures which developed when water leaking from the illfitting sections of corrugated pipes seeped through the sand into the fissured clays.

The largest slumpblocks, however, were located where one drain protruded out of the sand at the edge of the bluff. Besides the contributing effect of the weight of the seepage water load and build-up of pore pressures, failure here was quite possibly a result of wetting the lower, stiff dry clay, which was buttressing a relatively steep slope. Wetting reduced the strength of the buttress, thereby causing the failure.

Where the highway has been cut through silty clay between Port Cartier and Rivière Vachon (locality 15) very small shallow bowls can be seen in the cut bank. The scars are related to downslope movement of clumps of vegetation and soil which break off either at the top of the bank or along the slope, probably during storms. The weight of the sodden root and clay mass, wetting of the slope, and vibrations from large transport and gravel trucks allow the vegetation clumps to move downslope and to pull away the outer layers of the soil over which they move, leaving a small bowl where the vegetation was originally rooted, and a shallow trough downslope.

4. Slope failures at Sept-Iles, June-September 1972

Active bank failures and flows occurred at Sept-Iles (locality 10). Unstable conditions at four small new slides were observed along a bluff at the north end of the city on June 27 and September 23, 1972.

Stratigraphy at the landslide site The bluff consists of about two metres of very coarse, well-sorted, brown, bedded sands, which sharply truncate six to seven metres of apparently massive grey clayey silts (25% by weight is less than 2μ). The sands are part of a wedge of beach deposits (shown in Figure 4-14) whose upper surface is almost horizontal, but whose lower boundary steadily slopes down to the southeast. The sands consist of quartz and feldspar with occasional dark iron-enriched bands. Leaching appears to be restricted to the upper 30 cm (the A_1 soil horizon).

The clays are former massive marine deposits which extend to bedrock at -60m. Molluscs, chiefly Mya arenaria and Macoma calcarea, are found intact within the clay. X-ray data indicate that quartz and feldspar are the principal minerals. Amphibole and possibly illite and chlorite also may be present.

The base of the bluff is a clayey platform which slopes gently into the tidal flat. The lower part of the bluff is oversteepened in some places as a result of wave and tidal action.

Slide morphology Slide scars extend over the total bluff height, approximately eight metres. The widths range from four to ten metres. Depth (horizontal) depends on the shape of the scar, but the maximum projection of the slides is 3/4 the slide width. The slides are separated by spurs where they are close together or near older slide scars, or by stable, vegetated slope segments.

The spurs can be considered as stable zones in that they do not fail at the same time as the adjacent material. Spur zones observed in 1969, however, are now slide zones, while the old scars, now slump covered, have become the "stable" areas. In profile the spurs are usually straight sloped (Figure 7-12). The upper facet is 32 to 38°, while the triangular frontal face stands at about 58°. Areas of no failure have similar slope configuration. Where old slides are partially buried by loose sand, the sand-covered slopes rest at 34°.

Large blocks which have sloughed off during failure lie along the failure plane, near the base. These segments show few signs of disturbance. Edges are rounded and sand coats the clays, but bedding is intact and the vegetation is in growth position. The tree tops point inwards towards the backwall, indicating that the base of the block has rotated outwards at the time of failure. Between the slump blocks and the backwall, drainage is impeded. Pools of muddy water and very soft clay are found in this area.

Aprons of sediment extend as far as 25 m from the slides. They consist of amorphous clay with "inclusions" of small blocks possibly produced by the shattering of larger blocks and mudballs. Where vegetation is still rooted into the blocks, tree tops are pointed outwards,

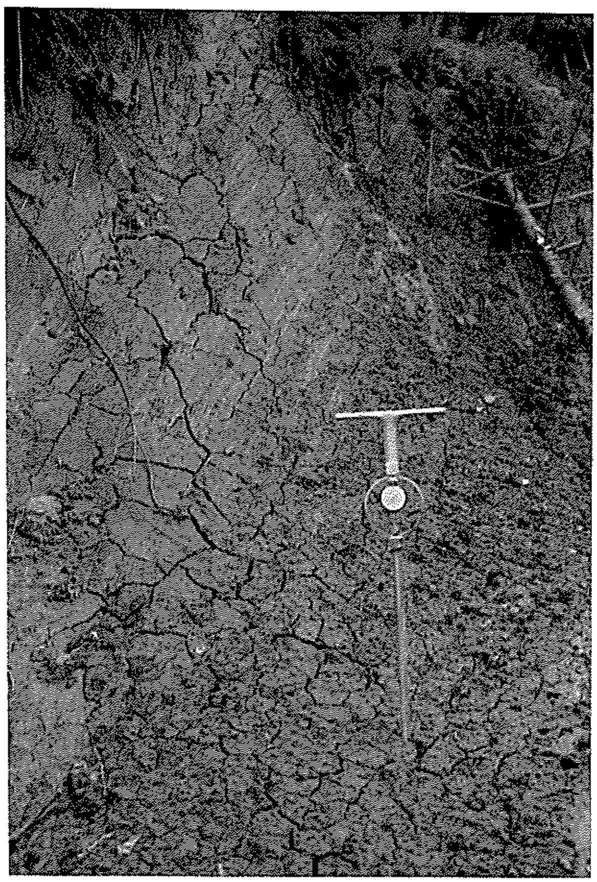
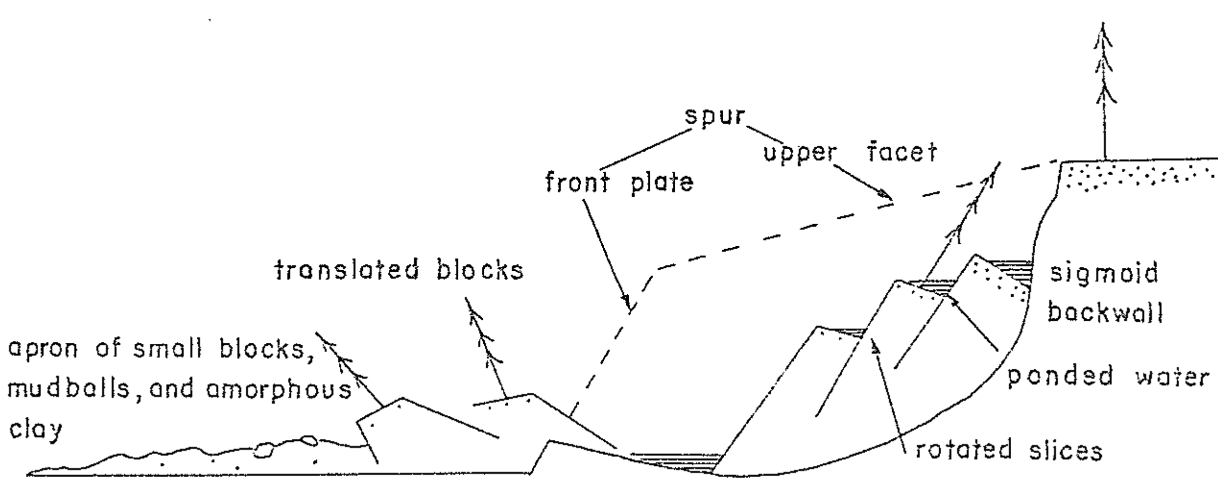


Figure 7-11 Sidewall of one of the landslides at Sept-Iles. Material is massive silty clay. Note desiccation cracks and remnants of slickensides. Proving ring penetrometer is one metre long. Photo taken in 1974, two years after the slide occurred.

Figure 7-12 Schematic configuration of slides at Sept-Iles



indicating that the material carried by slurry at some time rotated in the direction of the translation.

Characteristics of the clays: summary of index properties Samples were collected on September 23 for the lab analyses indicated below (Table 7-2). Three of the slides probably occurred on June 26, following 6½ cm of rain on the 23 and 25th. The fourth slide failed on September 4 after 10 cm of precipitation fell in 12 hours.

Visual observations When any instrument such as a knife, sampling tube or shear vane was inserted into the clays the adjacent material remoulded to a slurry. In addition, when the shear vane (4 cm in length) was used, the shearing stress produced strength losses for the radius of about 10 cm.

There was no desiccation crust in 1972 like that observed in other years. The outer five centimetres were beginning to dry out, however, and on removal, the vane was always coated with sticky, remoulded clay. Beyond this depth the stickiness decreased and on removal the vane was coated with a mud slurry.

Strength measurements Strength values were obtained using a Geonor vane at distances of 0 to 50 cm in from the face at different depths on the 10 m high face of the bluff, and on the slumped material. A pocket penetrometer was used for estimations of unconfined compressive strengths.

The shear strength at failure varied from two to six t/m^2 (0.2 to 0.6 kg/cm^2), but was usually near $3.5 \pm 0.1\ t/m^2$ (0.35 kg/cm^2). There was no systematic change with distance in from the bluff or along the bluffs vertically and horizontally. The remoulded strength, taken one minute after shearing, was virtually zero in all cases. Sensitivity under the present

Table 7-2 Index properties of clays at the Sept-Iles landslides, 1972

Sample	w%	WL	Wp	% clay	I_L	I_P	Activity	Bulk dens.(g/cc)	Dry dens.	Soil class
test	33	28	20	25	1.6	8	0.3	1.55	1.03	CL
1-1	37	34	24	(av. of 2	1.3	10	0.4	1.59	1.00	CL
1-2	38	33	20	samples)	1.4	13	0.5	1.64	1.02	CL
1-3	26	33	22		0.4	11	0.4	1.81	1.34	CL
2-1	32	30	14		1.1	16	0.6	1.95	1.32	CL
2-2	37	31	21		1.6	10	0.4	1.91	1.21	CL
2-3	29	29	22		1.0	7	0.3	1.81	1.28	CL
2-4	35	35	23		1.2	12	0.5	1.87	1.20	CI
3-1	16	32	28		---	4	0.2	1.81	1.49	ML
3-2	44	46	25		0.9	21	0.8	1.67	0.94	CI
average	33	33	20		1.0	11	0.5	1.76	1.18	CL

Comparative index properties from other areas

	Sample	w%	WL	Wp	% clay	I_L	I_P	Activity	Bulk dens.(g/cc)
Toulnustouc	5-2	36	25	20	30	3.6	4.6	0.15	
Conlon, 1966									
Moisie valley		37	34	19	--	1.3	15		
Pryer and Woods, 1959									
Nicolet									
Chagnon, 1968		40	56	21	70	0.5	3.5	0.5	
Crawford and Eden, 1967		65	55	23	50-70	1.3			
Ottawa lower			20-45		42	1-4	5-20	0.2	1.84
Ottawa upper			60-85		80	0.5-1.2	60-35	0.5	1.64
Soderman & Quigley, 1965									

conditions is thus extremely high.

Strength values were similar for the slide face, translated material, and stable parts of the bluff.

Measurements were taken on blocks from both the top and sides but no differences in shear strength were apparent. It thus appears that the strength is isotropic, although on dried samples in other areas, vertical strength exceeded the horizontal strength.

Unconfined compressive strength values for the face range from 0 kg/cm^2 (i.e. continuous yield) to 3 kg/cm^2. The average for a cleaned face (i.e. where the surface was scraped to expose a flat area for testing) was 0.3 kg/cm^2, while on the undisturbed surface it averages about 1.6 kg/cm^2, particularly where sand grains were admixed with the clays on the sides of slumped blocks. This value is greater than for the average results here but less than surface strengths in other areas, which exceeded 5 kg/cm^2.

The strength values obtained here fall near the lower limit of the measurements reported for marine clays in the Ottawa-St. Lawrence lowland (range is 0.2 to 1 kg/cm^2). They are much less than those reported for the Moisie River (Pryer and Woods, 1959) and the Tounustouc estuarine deposits (greater than 4 kg/cm^2) (Conlon, 1966).

These observations suggest that failure results from disturbance, sudden loss of strength, and deformation when the material is subject to even small stress increments. The association of heavy rainfall and landslide activity suggests that the moisture regime is a major factor in slides.

The problem here is not why failures occurred, but rather why they are so limited, since:

1. the material fails under low stresses, even three months after the initial slides occurred
2. only a small increment is needed to exceed the critical stress because

small disturbances (while making observations) produced failures

3. the non-failed slopes have the same strength characteristics as those which had recently failed. Slope geometry differs somewhat, but the bluff height and apparent moisture conditions are the same throughout. Under the wettest conditions, the critical height of the bluff is about 6 m[1]; therefore, the eight-metre-high bluff is inherently unstable.

One factor which may be important in determining the location of slides at Sept-Iles when other conditions are critical is the uprooting of trees along the bluff. During the storm of September 4, easterly winds blew down trees atop the bluff; these subsequently fell upon and slid down the slope. Since walking on the face was sufficient to induce a slide, then the shock of a tree hitting the slope may have had similar effects. If so, then, the location of the slides initially depends on where the trees were knocked down the bluff, and the dimension of the failures would be determined by (a) the extent of the root system and (b) the length of time or distance involved in dissipating the effect of the stress (in terms of drainage rates and particle adjustment time).

5. Landslides and earthquakes

The southern part of the field area has one of the highest earthquake probabilities in Canada (Stevens and Milne, 1974, Figure 1). These quakes are generated by crustal adjustments along faults paralleling the St. Lawrence Valley. Since 1928, eight epicentres have been located within the field area (Smith, 1966) and the effects of numerous others originating

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[1]Value calculated from the equation $H_c = N_s \frac{c}{\gamma}$, which determines the critical height (H_c) of a toe failure. Under conditions of $\phi = 0$, $N_s = 5.4$ for slopes of 58^o; $c = 0.2$ kg/cm^2, and $\gamma = 1.7$ g/cc; and H_c therefore equals 6 (metres). When a value of $\phi = 34^o$ is used, however, the critical height of the bluff is extended to 20 m.

farther afield were felt and reported by people in the area.

The annotated list of earthquakes in Quebec shows that tremors are often accompanied by landsliding of the postglacial marine clays (Smith, 1962 and 1966). As early as 1927 Hodgson reviewed slides described by Ells, Laflamme, Logan, and Dawson. He noted that although the slides resulted from drainage problems and that most slides were preceeded by heavy rains, minor earth tremors are often sufficient to precipitate slides at times when the slopes are conditionally unstable. He stressed the importance of seismic investigations in these areas, but his advice is generally ignored.

Although excess pore water pressures alone can produce slope instability and induce slope failure, the possible contributing role of earthquakes should be kept in mind. At Sept-Iles, the slope failures which occurred between the fall of 1971 and the summer of 1972 may have been induced by the tremor which occurred that spring.

7.4 Summary of the Principal Engineering Characteristics of the Geological Units

The following description, accompanied by Table 7-3 summarizes those physical and index properties of the map units which relate to engineering problems in the area.

Till is the most abundant unconsolidated surficial deposit on the upland. Texturally it is a poorly sorted sandy gravel, and there are very few fines. This material is classed as GW or SW in the Unified Soil System, depending on the screens used in the grain size analysis. Since the material is non-cohesive and its behaviour is non-plastic, the strength of the till is entirely dependent on its frictional properties. No laboratory strength determinations were made on till samples from the field area, but Dussault *et al.* (1970) report that the strength of similar till at the Outardes 4 dam

Table 7-3 Summary Characteristics of the Geological Materials

Ratings Related to Engineering Uses

Geological Material	Field extent	Unified Soil Classification [1]	Workability as a Construction Material [2]	Rating as a Subgrade [3]	Compressibility when compacted [4]	Shear strength when compacted [5]	Bearing Strength kg/cm^2 [6]	Frost Susceptibility [7]	Drainage Characteristics [8]	Av. natural Water content	Dry density at Optimum compaction g/cc [9]	Remarks
till	widespread on uplands	GW-SW	excellent	good-excellent	11	excellent	2.1	nil	excellent	6%	1.40	no cohesion
outwash	limited on coastal plain extensive in large valleys	GW	excellent	good	nil	excellent	3.3	nil	excellent	6%	1.45	wide range in characteristics
massive & banded clay	widespread below the marine limit. Does not outcrop except at Sept-Iles	CL	fair	poor	moderate	fair-poor	0.7-1.8	high	poor	38%	1.15	high sensitivity; subject to landslides
nearshore sand	widespread in the delta formations. Not expressed at surface	SM(SF)	fair	fair-good	low	good	1.3-1.7	low, occas. mod.	moderate-good	5-15%	1.20	subject to accelerated erosion when disturbed
beach sand	surface materials below 140 m asl	SP(SU)	fair	excellent	very low	good	1.4-2.7	nil	excellent	<5%	1.15	--
muskeg	deep and widespread on coastal plain. Very limited on uplands.	Pt	very poor	very poor	extremely high	poor	---	slight	poor	1200%	--	> 80% organics, very fibrous
dune sands	very limited	SP(SU)	fair	excellent	very low	good	1.4-2.7	nil	excellent	2%	1.15	--
tidal flat sediment	limited to Sept-Iles area	OL-CL	fair	poor	moderate	fair-poor	0.7-1.8	high	very poor	33%	1.15	diurnally flooded
alluvium	common in valleys limited extent	variable	fair	variable	low	fair	variable	variable	good	variable	variable	--

Sources:

1. ASTM 1964

2, 4, 5 Lambe and Whitman 1969 p. 37

3, 6, 7, 8, 9 Gt. Britain Road Research Laboratory 1959 pp. 66 and 81 site ranges between 7 and 10 kg/cm^2 over the natural water contents, and the effective angle of internal friction was 35^o to 42^o. *In situ* penetration resistance was measured using a hand-held proving ring cone penetrometer. The resulting penetration values range from 2 to 6 kg/cm^2 but average 4 kg/cm^2. The *in situ* density therefore appears to be "medium" to marginally "dense". Judgingby field observations after rainfall, the till has a high permeability, ($k = 10^{-2}$ to 10^{-4} cm/sec) according to Beard and Weyl's tables (1973). Natural water contents are less than six per cent of the dry weight on well drained sites but in low areas the till may be saturated. The *in situ* water contents appear to be two to four per cent less than the optimum value of similar tills (Dussault *et al.*, 1970; Eden, 1976).

Till can be used for subgrade or earthfill if the large boulders frequently encountered are removed. The material is not susceptible to frost heave. Since the depth to bedrock is commonly less than 2 metres, some construction difficulties may arise in upland areas; low road grades must be maintained by blasting through bedrock rather than by using simple cut-and-fill techniques within the overburden.

Outwash is typically coarse grained cobbly gravel (GW). There are numerous textural variations related to energy conditions at the time of deposition but generally the material is poorly sorted. As with till, the permeability is high. Because of its texture and Precambrian mineralogy, the outwash provides a good source of aggregate; frost susceptibility is negligible. The very large boulders common in the till are absent in outwash gravels.

Offshore marine deposits are poorly sorted clayey silts of low plasticity (CL). The activity of these clays is also very low. Clay deposits are quite thick but are generally covered by a blanket of beach or nearshore sand from 2 to 20 m thick.

Along river banks, exposed clay faces are dry, stiff, brittle and have shear strengths exceeding 5.0 kg/cm^2. In the subsurface the clays are soft and very sticky. Field values of vane shear strength on active slopes vary from 0.2 to 0.6 kg/cm^2 and there are no systematic strength changes with depth. In the banded unit the resistance to shearing is lowest parallel to sand partings; massive deposits have isotropic shearing characteristics.

The liquid and plastic limits are approximately 32% and 19% respectively, and natural water contents exceed 38%. The clays are moderately to highly sensitive.

Consolidation tests from borehole reports indicate that the clays are moderately to highly overconsolidated, although the slope of the consolidation curves suggests that this "apparent" overconsolidation may be due to bond cementation in the soil framework.

The permeability is low, probably less than 10^{-7} cm/sec (Lambe and Whitman, 1969), and because of the silty nature of the material it is probably susceptible to frost heaving.

Under poor drainage conditions, or heavy rainfall, exposed clay slopes are subject to failure. These tend to take the form of semicircular rotational slips and flowslides. Areas most prone to landsliding (besides riverbanks where undercutting occurs) are zones where excess porewater pressures can develop rapidly: i.e. where drainage paths are disrupted by natural or man-made structures within the clays.

<u>Nearshore</u> materials are fine, grey, micaceous, well sorted, non-cohesive sand (SM/SI grading upwards in exposures to SP), grading in some places to silty sand. Soils of this type are plentiful below the beach sands in the large delta formations which dominate the coastal plain. Some of the deposits are susceptible to frost heaving, so care should be exercised when using this material in construction. The sands are permeable (measured value of

$k = 5x10^{-3}$ cm/sec) but less so than beach sands. Where strata are discontinuous or disrupted by clay laminae, unstable conditions may develop after heavy rainfalls.

Beach Sands are the surficial material over most of the coastal plain. Their depth is usually two to five metres; they grade downward into finer nearshore deposits. The soil consists of well sorted brown sand and is classed in the SP (SU) category; there are no fines. The soil drains rapidly and the calculated coefficient of permeability (k) is $1x10^{-2}$ cm/sec. The material is suitable as foundation substrate or as subgrade, and is not susceptible to frost heaving.

Organic terrain covers a significant percentage of the coastal plain on the Sept-Iles map sheet, where it overlies beach sands to a depth of four metres. The peat is fibrous at the surface but becomes increasingly amorphous with depth. Water contents are extremely high and the material is very compressible. The strength characteristics are apparently isotropic, but no actual strength values were determined.

Floating corduroy lumber roads in the area have undergone considerable differential lateral shifting and vertical settlement. Differential settlement commonly associated with road construction can generally be eliminated by using temporary surcharges (Samson and LaRochelle, 1972), drainage, or by replacement of the peat with inorganic subgrade.

Aeolian dune sand is extremely limited in the field area; the properties of the material are very similar to beach sand.

Alluvium is also limited in area but its properties are variable. Gravelly point bar deposits are useful sources of aggregate and subgrade for roads being constructed along major river valleys, but finer flood plain alluvium may contain sufficient fines to render it frost susceptible.

8 CONCLUSIONS AND RECOMMENDATIONS

The major conclusions from this study are:

1. The principal Quaternary deposits, in stratigraphic sequence, are till, outwash, a marine offlap sequence of clay grading to sand, and bog deposits.
2. There is evidence for only one glaciation in the area, which probably spans at least the middle and late Wisconsinan. Ice related to this event advanced from north-northwest.
   Indirect evidence from this study, together with data from other parts of the Gulf of St. Lawrence, suggests that middle and late Wisconsin Laurentide ice did not extend far beyond the field area.
3. Deglaciation occurred about 9300 years ago. It was characterized by northerly retreat of an active, warm-based ice mass, and by the deposition of a thin blanket of sandy till of local provenance. The morainic systems produced are a series of minor moraines located west of Baie Trinité, and a series of ridges which extend from Lac Dionne in the west to Lac Daigle in the east.
4. The marine limit in the Sept-Iles area is at 130 m ASL. The limit decreases to the south and west to 100-110 m near the village of Franquelin.
5. The principal engineering properties of Quaternary materials are summarized in the text. Sediments associated with the marine regression are especially important; in particular, the distribution and engineering characteristics of sensitive marine clays must be appreciated before industrial development continues along the North Shore.

The major recommendations based on this study are:

1. In projects of this sort, areas around developing settlements should be mapped at a scale of 1:50,000 rather than at 1:125,000. The smaller

scale is suitable for mapping the outlying regions, where detailed information is more difficult to obtain.

2. Trail bikes or Honda ATVs should be used for inland access on lumber roads.

3. Radiocarbon results suggest that postglacial emergence in this area can only be accurately described by a series of curves whose slopes decrease from northeast to southwest across the area. Additional radiocarbon dating control is necessary to test this hypothesis and to enable results from the North Shore to be compared with Gaspé data.

4. Field examination of the heads of fiord valleys is required to refine the model for deglaciation in the area, and to acquire additional data on the elevation and dates of marine limits. In addition, it may be possible to find glacial and non-glacial stratigraphic sequences which predate the late Wisconsin in the incised valley deposits.

5. It should be possible to develop a general model for ice disintegration in an estuarine environment by using data from this thesis in combination with (1) a Fennoscandian analogue for Quaternary deglaciation in the Baltic, (2) theoretical glacial mechanics, and (3) a modern analogue based on present-day ice shelf behaviour in Antarctica.

6. Mineralogical traverses of the till were run perpendicular to the direction of ice flow, to establish the mineralogical diversity of the region. Flow-parallel data should now be obtained to complement this study and to determine comminution styles and rates for the rock suites found here.

7. A standardized method for the colour classification of garnets should

be devised if garnets are to be used efficiently for determining till provenance.

8. Problems with shear strength values measured during this research indicates that the value obtained depends on the type of instrument used. A study should be set up to compare results from (1) vane instruments and penetrometers, (2) small portable instruments (from which results can be obtained cheaply, even in inaccessible areas) and truck-mounted equipment (which supposedly yield better results but are costly or impracticle in many areas), (3) field tests and laboratory tests.

9. This study has suggested that lacustrine and marine rhythmites can be differentiated by textural analysis. A laboratory study should be set up to test this hypothesis because if valid, the technique could assist in determining the environment of deposition of non-fossiliferous deposits in problem areas, such as the Hudson Bay lowlands, where a complex succession of marine and lacustrine environments may have existed.

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APPENDIX A General Site Investigations

In the field, exposures were described according to the procedure of Scott and St. Onge (1969) for tills. Much of the sampling and testing was done at exposures along a traverse which runs northeast-southwest diagonally across the map sheets and normal to the direction of ice flow. The location of this traverse was determined by accessibility. Many of the samples were taken within 100 metres of either the roadway or secondary tracks. Sites were selected in an attempt to obtain representative data across the entire length of the field area, and in every type of surficial material; and to perform tests and obtain samples where the depth of the surficial deposits was greater than the depth of soil development. This greatly restricts the location of till sites because the till is often less than 2 metres thick. Till samples were also taken with a view to sampling adequately over both the major rock types.

Penetration resistance and vane shear strength were determined in the field. Five hundred to 1000 gm samples (and sets of 100 pebbles for tills) were extracted from cleaned exposures for analysis of water content, Atterberg limits, granulometric characteristics, mineralogy, and colour. *In situ* fabric measurements of the till were also undertaken.

Examination of materials, stratigraphic observations and sampling were done at natural exposures or excavations. Attempts at test pitting where there were no exposures met with very limited success. Augering was difficult because of the stoniness of the material; digging is impractical because of the thick root network and a soil hardpan in the upper metre.

APPENDIX B Till Fabrics

A series of till fabrics was planned along the main traverse (Route 138). The purpose was to obtain data on ice flow directions and gain insight into conditions of glacial transport and deposition by supplementing striae and textural data. However, only 13 three-dimensional fabrics were completed because data acquisition proved to be too time-consuming in view of the inconclusive nature of the results.

Fabrics were measured from cleaned till exposures about 2 metres below the soil zone. Between 80 and 100 pebbles were measured at each site. Elongate pebbles 1 to 3 cm long having the ratio of major and minor axes greater than 3/2 were used. As the elongate pebble was extracted a knitting needle was inserted into its mould and the orientation and plunge were measured to the nearest 5° using a geological compass. Orientations were plotted as 3-D lower hemisphere stereo plots and as 2-D rose diagrams.

Several problems arose from data extraction and its subsequent interpretation:

1. Only one of the plotted fabrics proved to have a statistically significant orientation at the 5% level.
2. Because of the nature of the parent bedrock a large proportion of the clasts extracted were almost equant. Elongate pebbles were rather difficult to find.
3. During extraction it was noted that pebbles were oriented along streamlined paths around larger clasts. This condition suggests that the resultant fabrics represent only responses to very local stresses within the ice, not regional forces.
4. The resultant fabrics were multimodal but the significance of the peaks could not always be determined from the auxiliary striae or textural data or

from the logic of the situation. Theoretically, measurement of both the orientation and plunge should permit the identification of the mode of flow within the glacier (transverse or longitudinal) and the style of deposition (ablation flow, basal melt out, or lodgement). These assumptions are not borne out by the field data.

The chronologic relationships of the multiple peaks also cannot be determined without better ancillary data. McClintock and Dreimanis (1964) have shown that ice lobes commonly splay out during retreat and presumably this directional change is reflected by reorganization of the till fabric; however, the extent to which this occurred along the North Shore is unknown at present.

APPENDIX C Mineralogical Determinations

C-1 General preparation of grains

Samples for mineralogical study were dry sieved. Subsamples were then soaked in a solution of .5N sodium hexametaphosphate for 24 hours and placed in an ultrasonic bath to disperse fine particles and shake off iron oxide coatings. They were later rewashed through the sieves and dried in an oven at 50°C. Heavy minerals were separated using tetrabromoethane (S.G. = 2.95). The light and heavy fractions were then mounted in Canada balsam on glass slides.

This procedure was followed for all fractions less than 1.41 mm, the diameter of the stop-cock openings on the heavy mineral separation apparatus, but because rock fragments are common in the +0.7 mm fraction, the grain counts in the coarse sand fraction are inaccurate. Grains between 0.032 and 0.25 mm were examined with a petrographic microscope using transmitted light. Those greater than 0.25 mm were studied under a binocular reflecting microscope.

C-2 Carbonate tests

Although large amounts of carbonate were not anticipated either in till or in marine materials, several tests were performed using the Chittick apparatus and method outlined by Dreimanis (1962). The samples chosen were those which were most likely to have carbonates; a) for tills, those which over-rode Grenville metasediments, including crystalline limestone, and b) for marine clays, those near the Paleozoic outliers at Sept-Iles, and another at Franquelin, which could have acquired carbonate because of its proximity to the Gaspé shore.

The test results indicate that there is no calcite or dolomite in either the marine clays or the till. This conclusion is substantiated by X-ray diffraction data.

One test was also run on a sample of fines from disintegrated anorthositic bedrock. The sample proved to have a small, but measureable calcite content (0.75 - 1.00%), but no dolomite. It is suggested that the calcite may be a weathering product of the anorthosite.

C-3 X-ray preparation and technical details

The mineralogies of the silt and clay fraction of tills and fine grained marine sediments were determined by X-ray diffraction analysis using a Philips diffractometer with Cu K_α radiation. Samples were scanned through 2° 2θ to 35° 2θ at the following settings:

time constant = 4 seconds

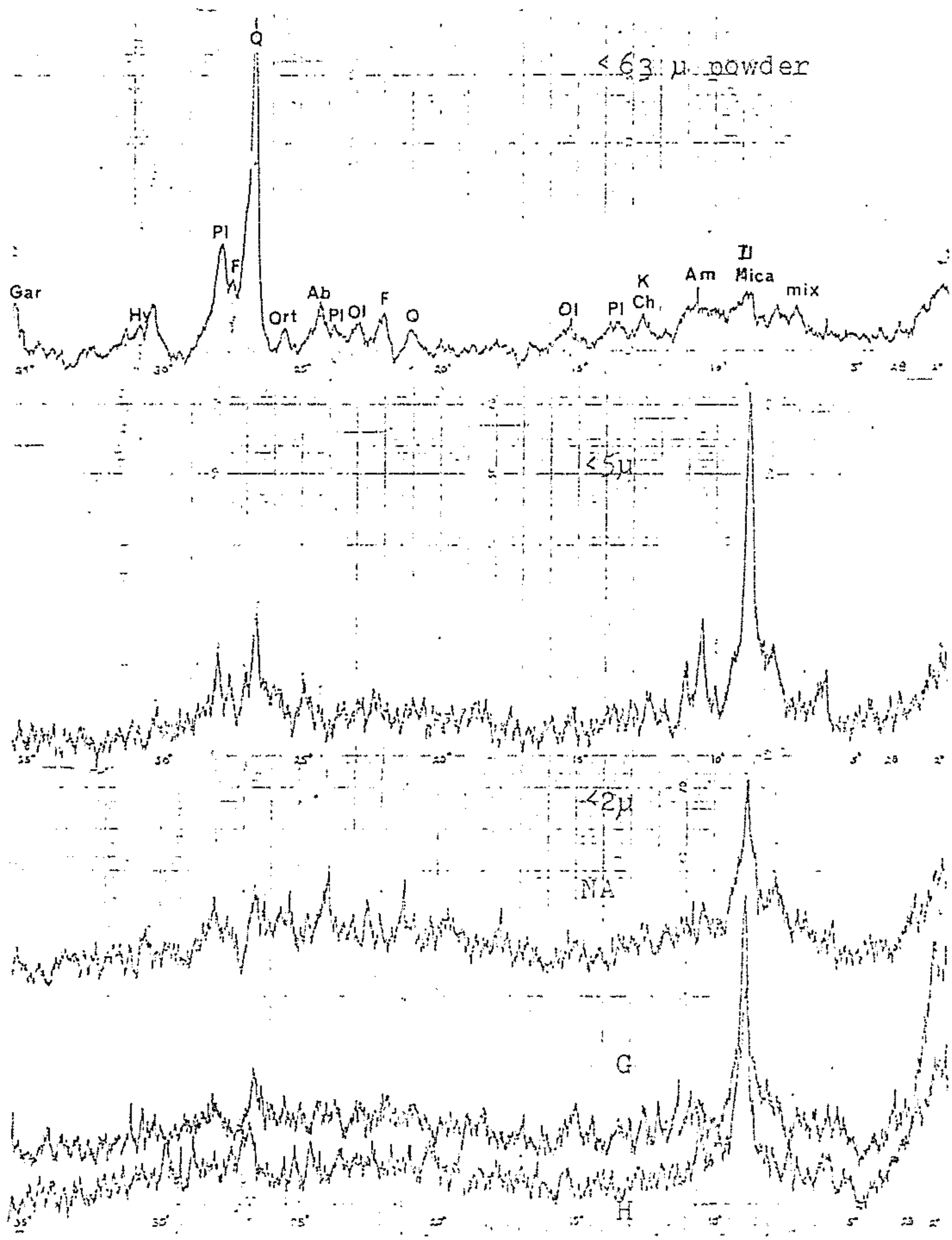
ratemeter = 1×10^2 cps

scanning speed = $.5^\circ$ / min

chart speed = 240 mm / hr

Specimens of the -63μ fraction were first run in a powder press. Samples were then separated into -63μ, -5μ and -2μ fractions by pipetting disaggregated suspensions at time intervals of 15 seconds, 60 minutes, and 4 hours respectively. The subsamples were dropped onto glass slides and then either air dried (NA on the diffraction patterns), glycolated (G) or heated to 550°C for one hour (H).

C-4 X ray patterns



< 63 µ powder
Q
Pl
F
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Ab
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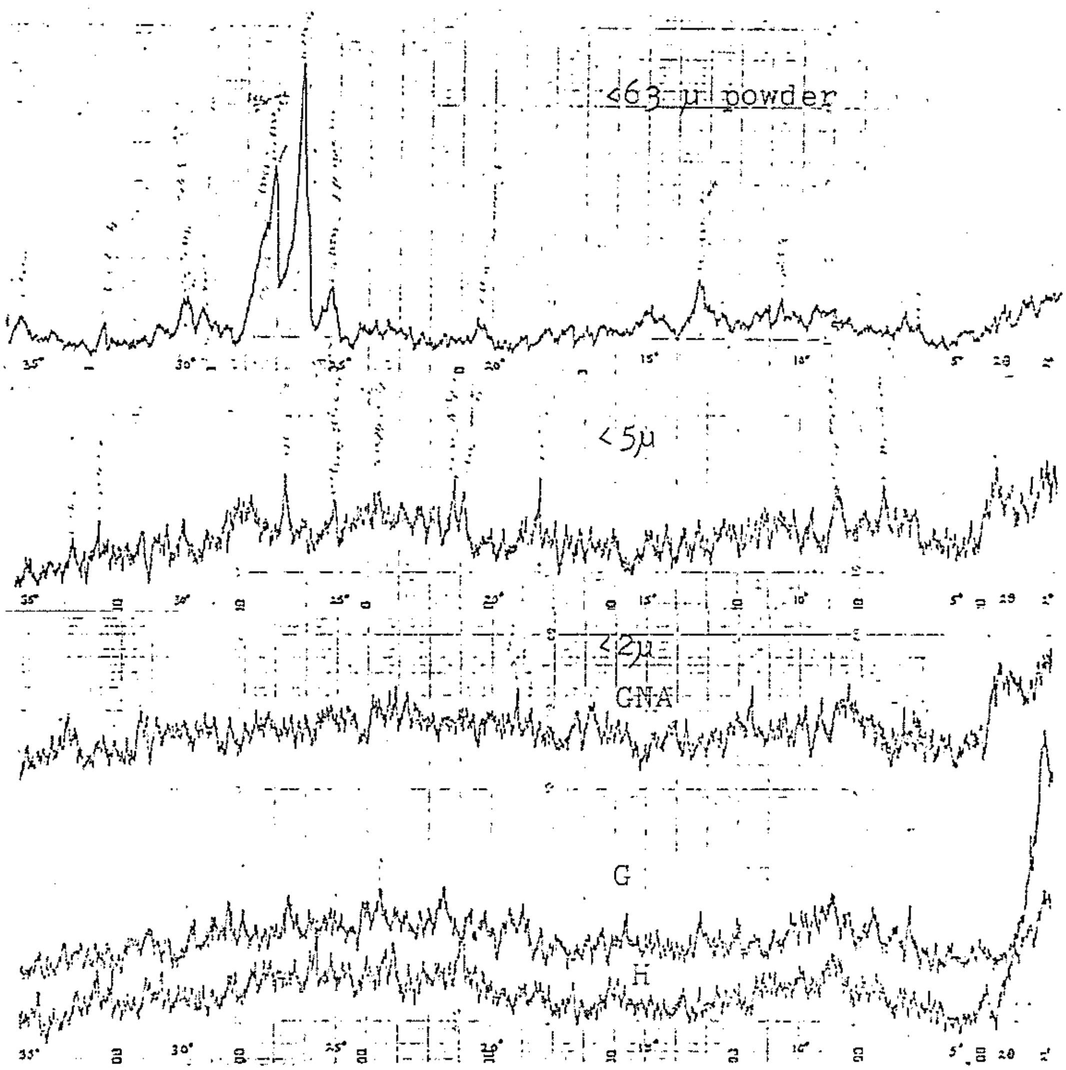
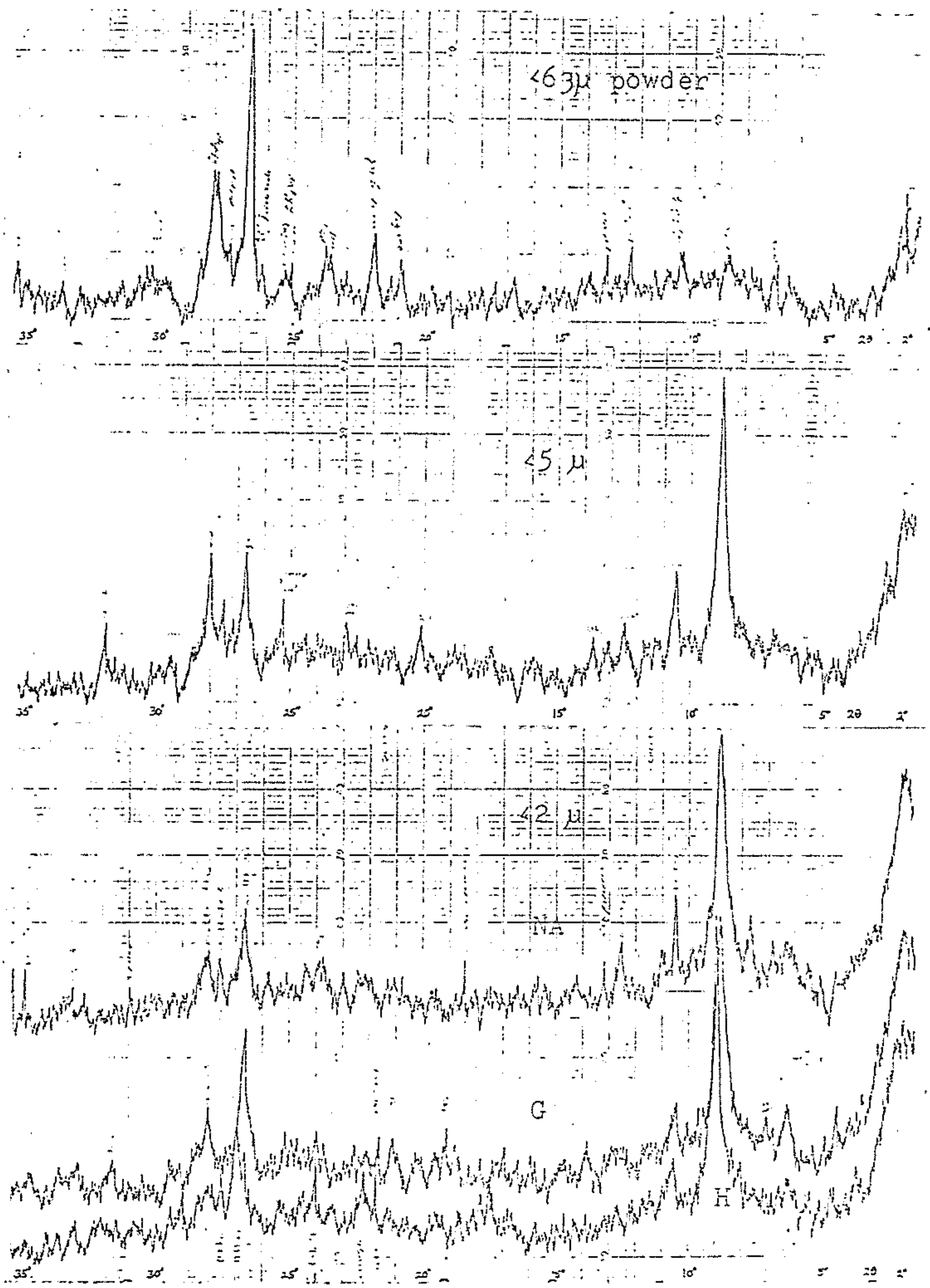
Am
Il
Mica
mix
< 5µ
< 2µ
NA
G
H

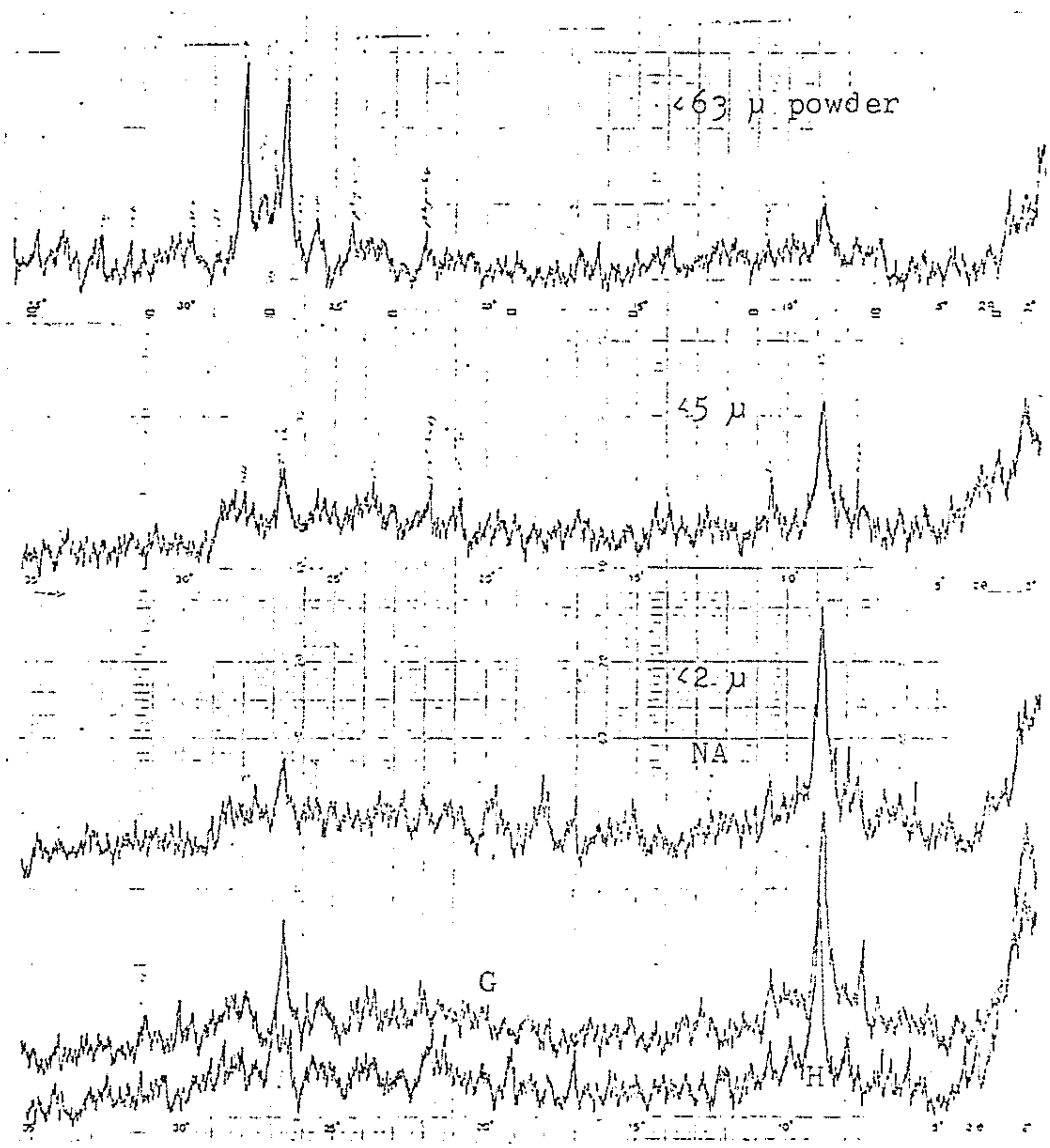
74-11 Mile 12



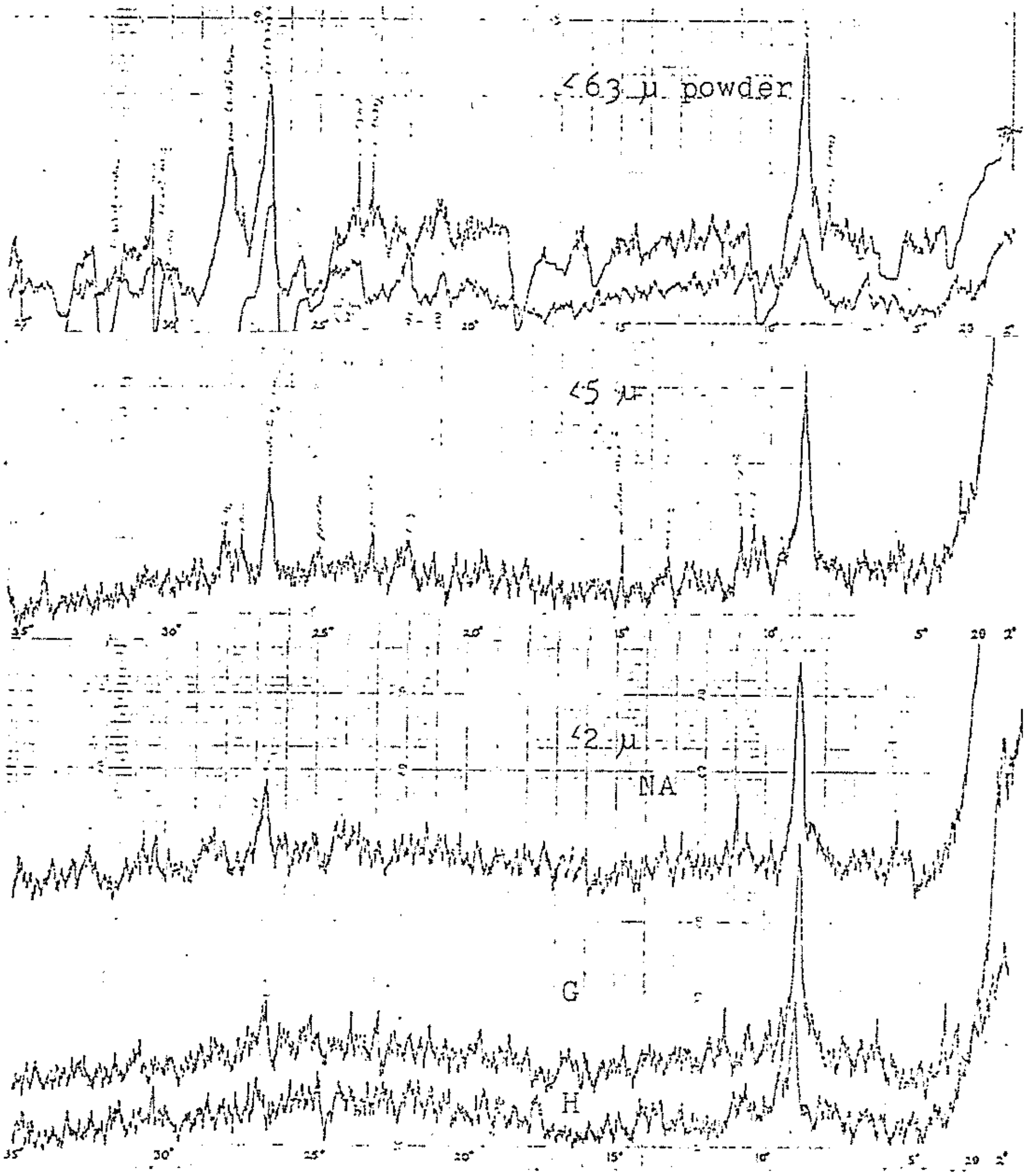
74-40 Dupont



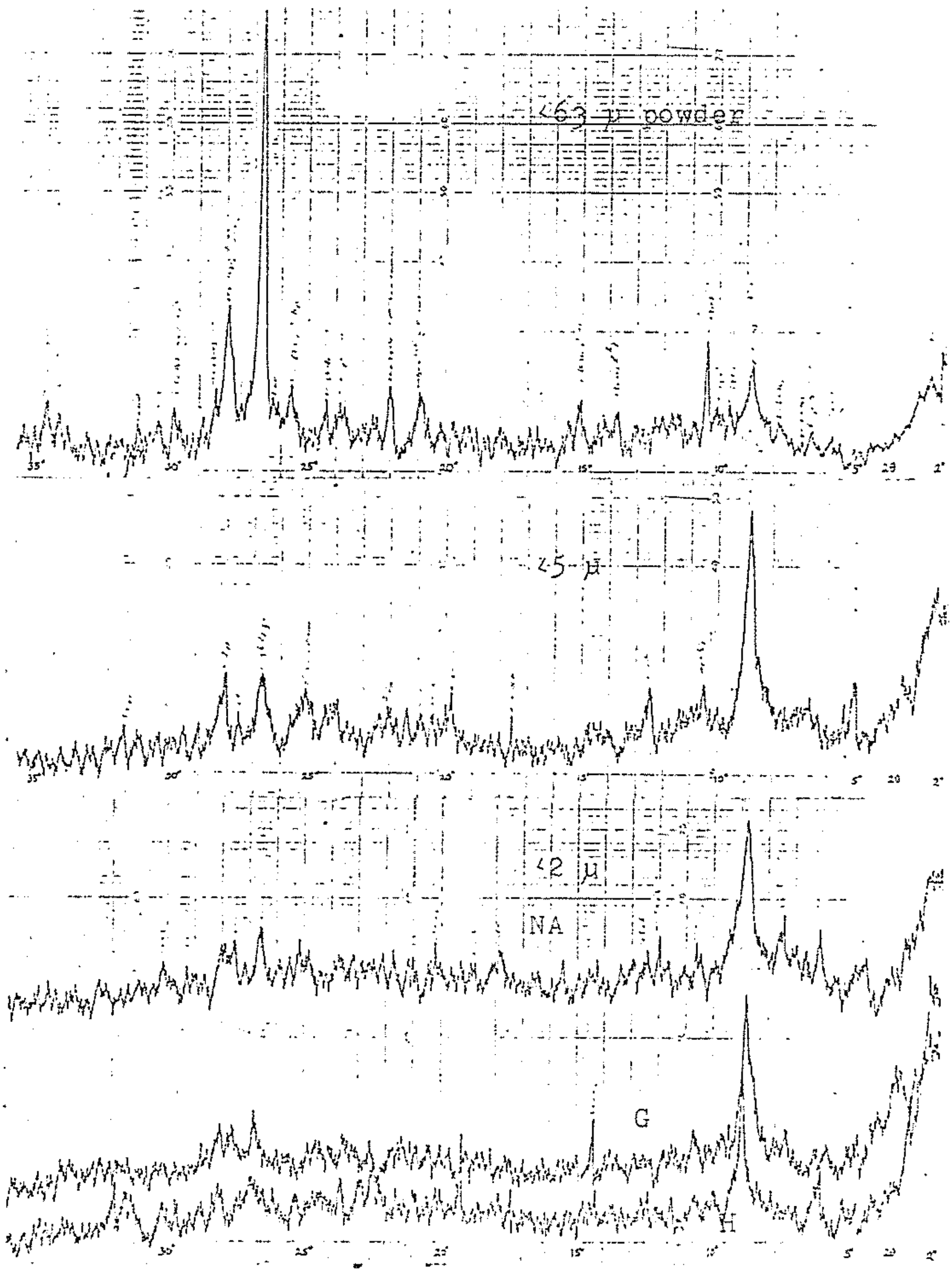
74-28 Sept Iles



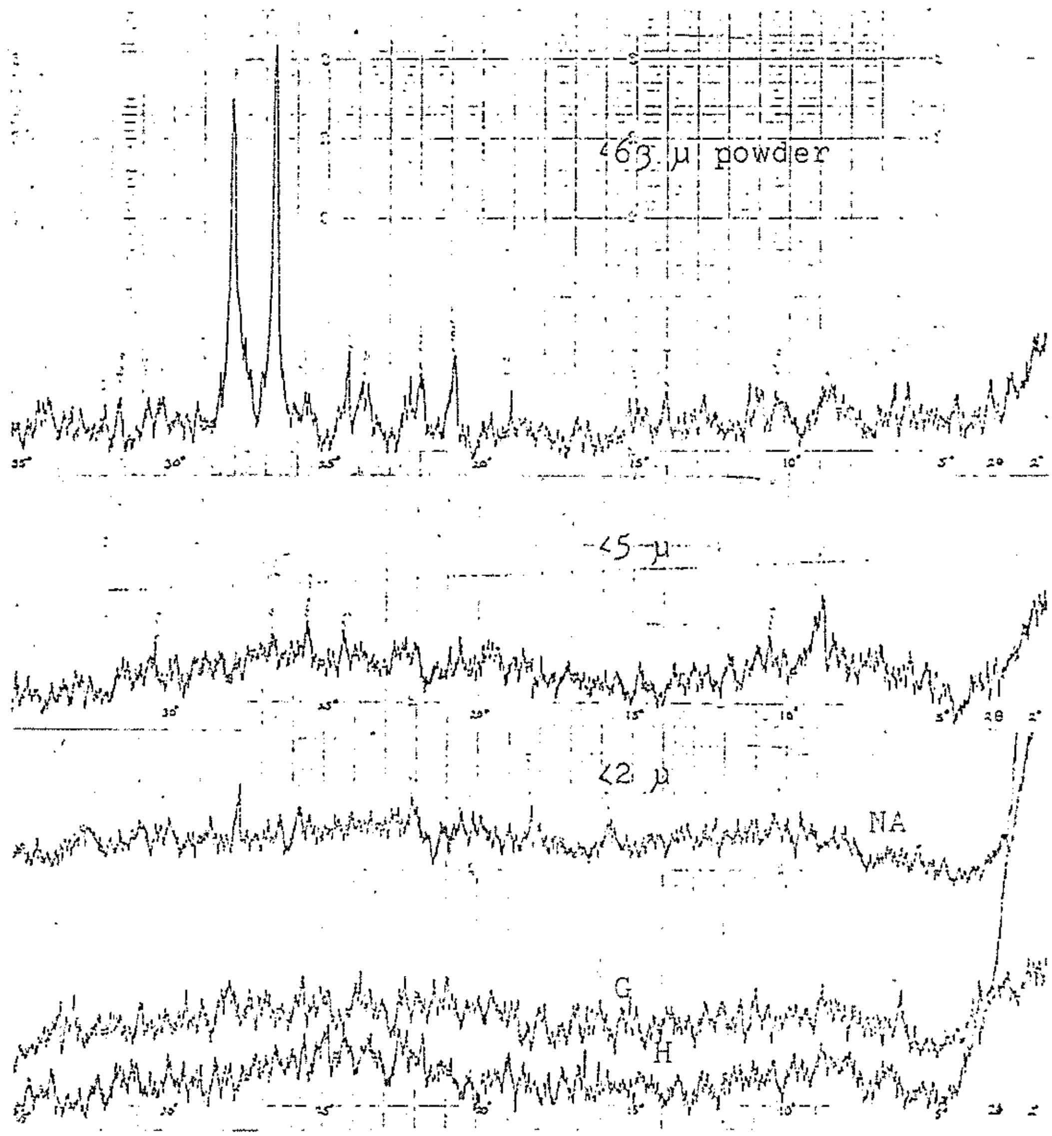
74-44 Mile 10



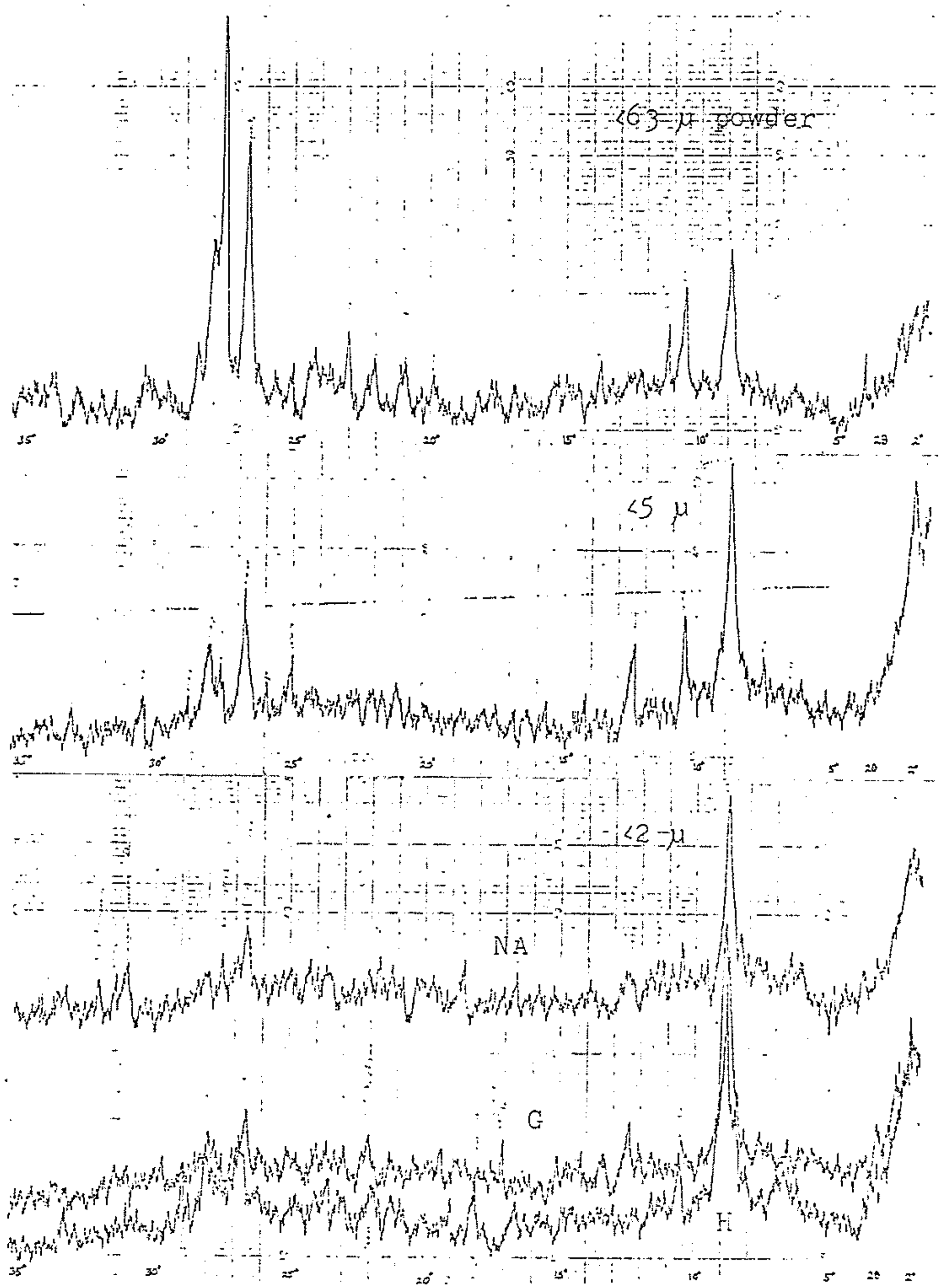
74-56 Port Cartier



74-42 Pentecôte West



74-81 Ilets Caribou



74-89 Baie St. Nicholas

APPENDIX D Grain Size Data

D-1 Analysis

The accompanying grading curves and tables illustrate the textural composition of the -4 mm fraction of field samples.

Particles between 4 and 25 mm were weighed, but excluded from calculations because the sample size (1000 gm) was too small to permit statistically representative results from the coarsest fraction. The remainder of the coarse fraction ($> 63\mu$) was air dried and dry sieved at $\frac{1}{2}$ Ø intervals. The size distribution of the -63 fraction was determined by hydrometer and pipette analysis of the dispersed sediment according to standard methods described by ASTM (ASTM, 1964).

The statistical parameters of mean, standard deviation, skewness and kurtosis were calculated according to the equations of Folk (1964, 43-47; 1966) as follows:

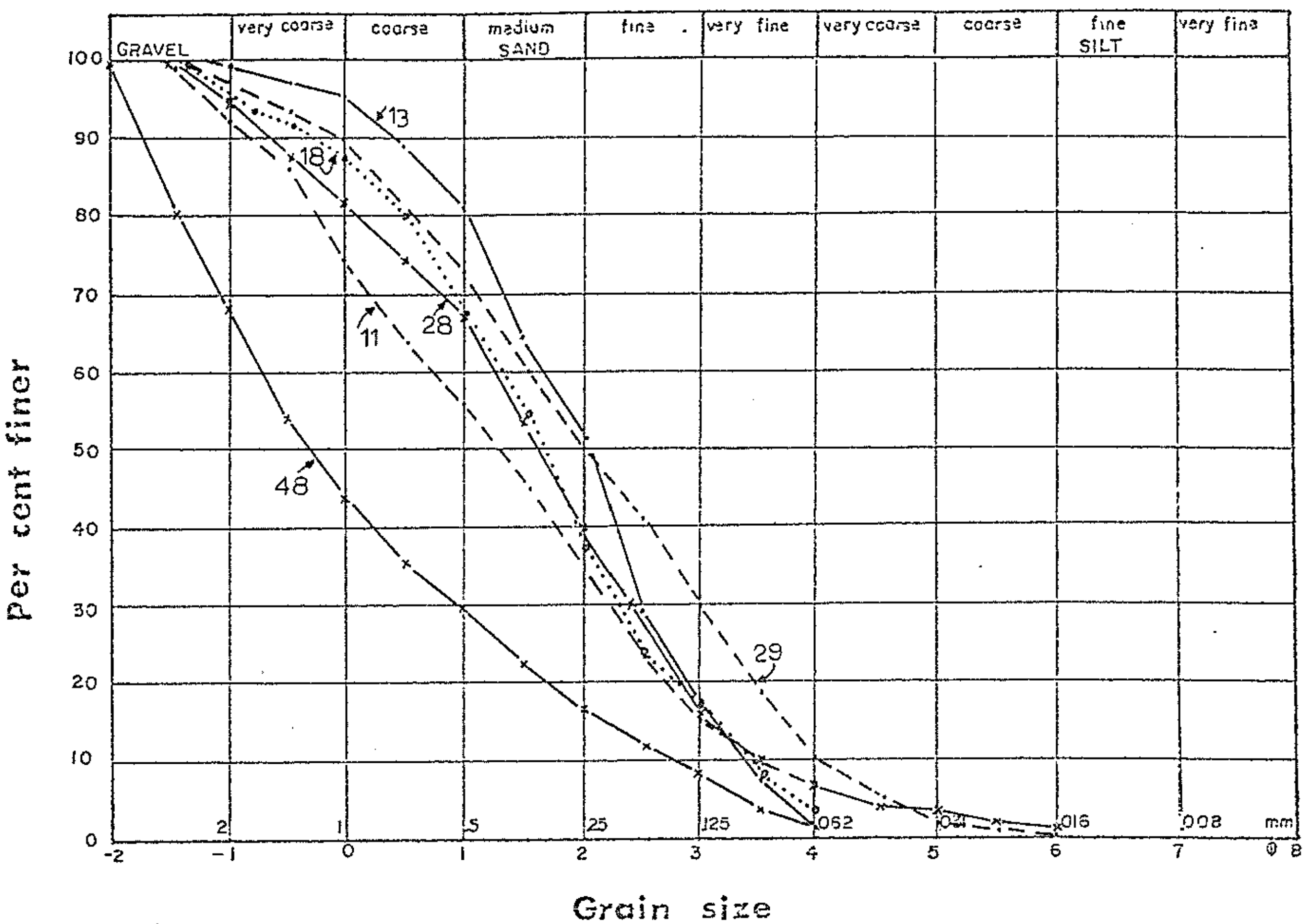
$$\text{mean} = (\phi16 + \phi50 + \phi84)/3$$

$$\text{standard deviation} = ((\phi84 - \phi16)/4) + ((\phi95 - \phi5)/6.6)$$

$$\text{skewness} = ((\phi16 + \phi84 - 2\phi50)/2(\phi84 - \phi16)) + ((\phi5 + \phi95 - 2\phi50)/2(\phi95 - \phi5))$$

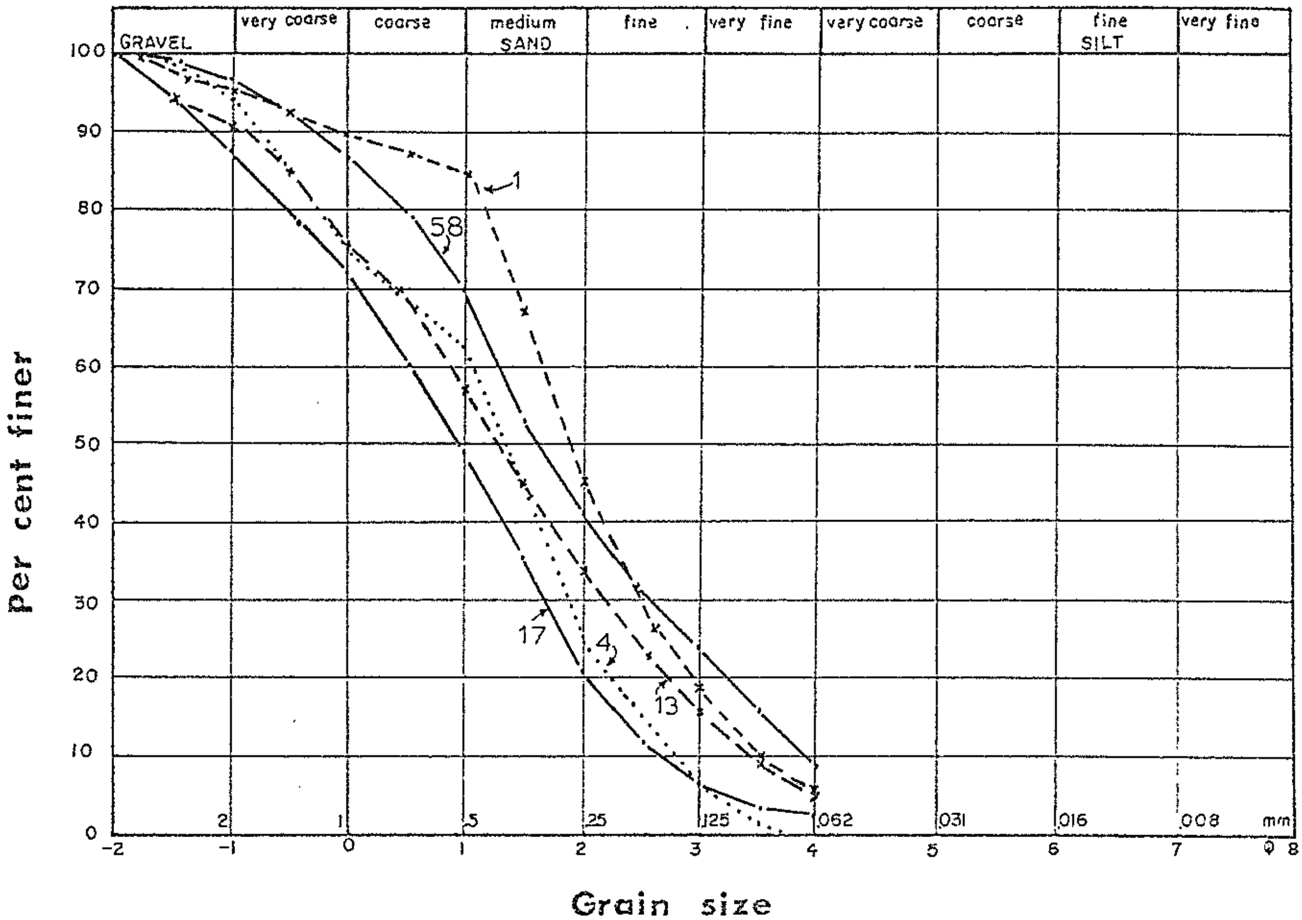
$$\text{kurtosis} = (\phi95 - \phi5)/2.44(\phi75 - \phi25)$$

D-2 Data



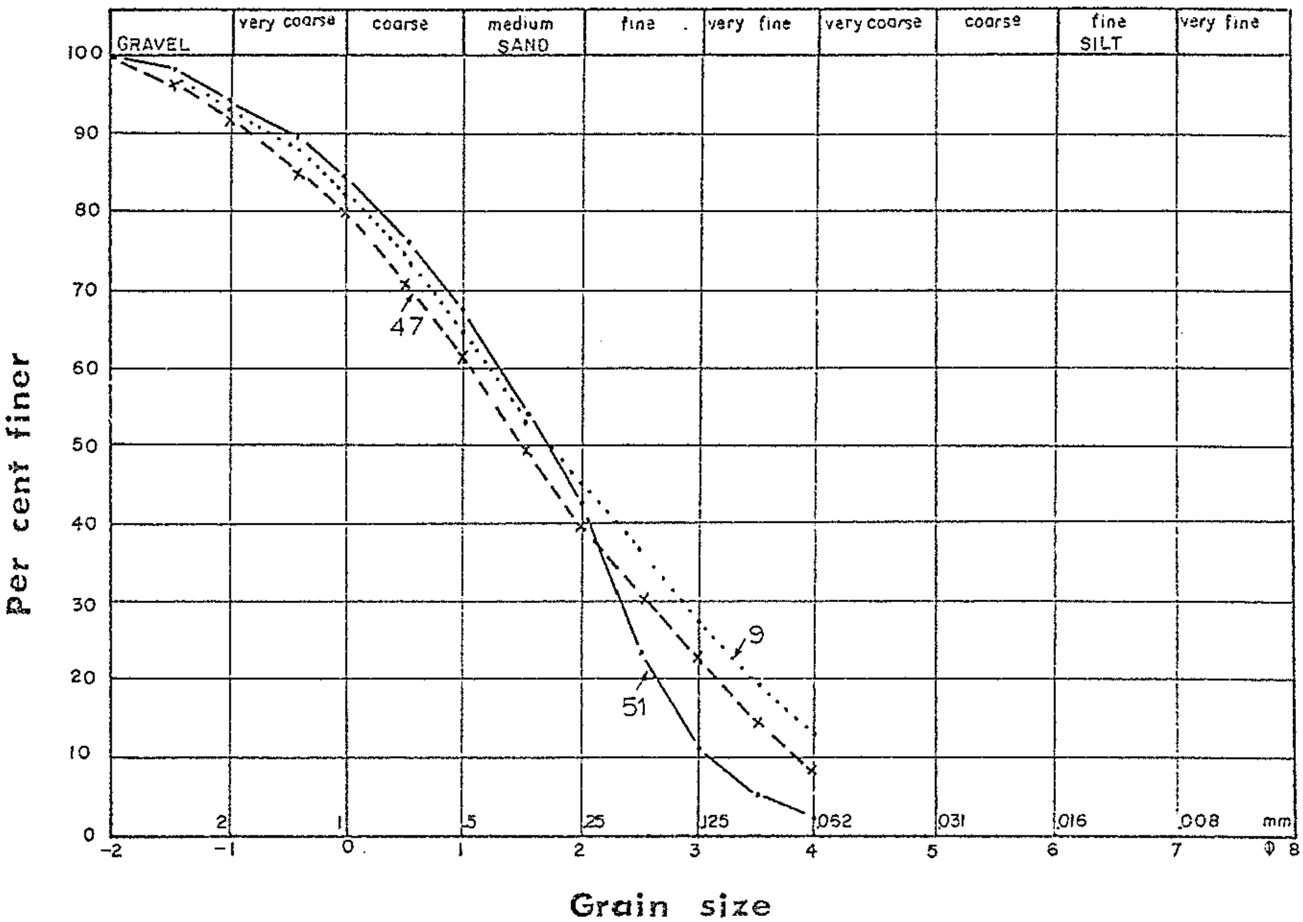
Till: Lac des Rapides mapsheet (22 J/ 8)

Sample Location	% gran	sand	si-clay	ϕ m	s	sk
69-28 Mile 12 L	6	88	6	1.47	1.52	-0.09
69-29 Mile 12 U	4	86	10	2.07	1.62	-0.02
71-13 Arnaud/Rapides	2	95	3	1.97	1.11	-0.09
72-48 Arnaud/Rapides	32	66	2	o.20	1.70	0.36
74-11 Mile 12	8	85	7	1.33	1.77	0.07
74-18 Powerline	6	90	4	1.57	1.48	-0.06



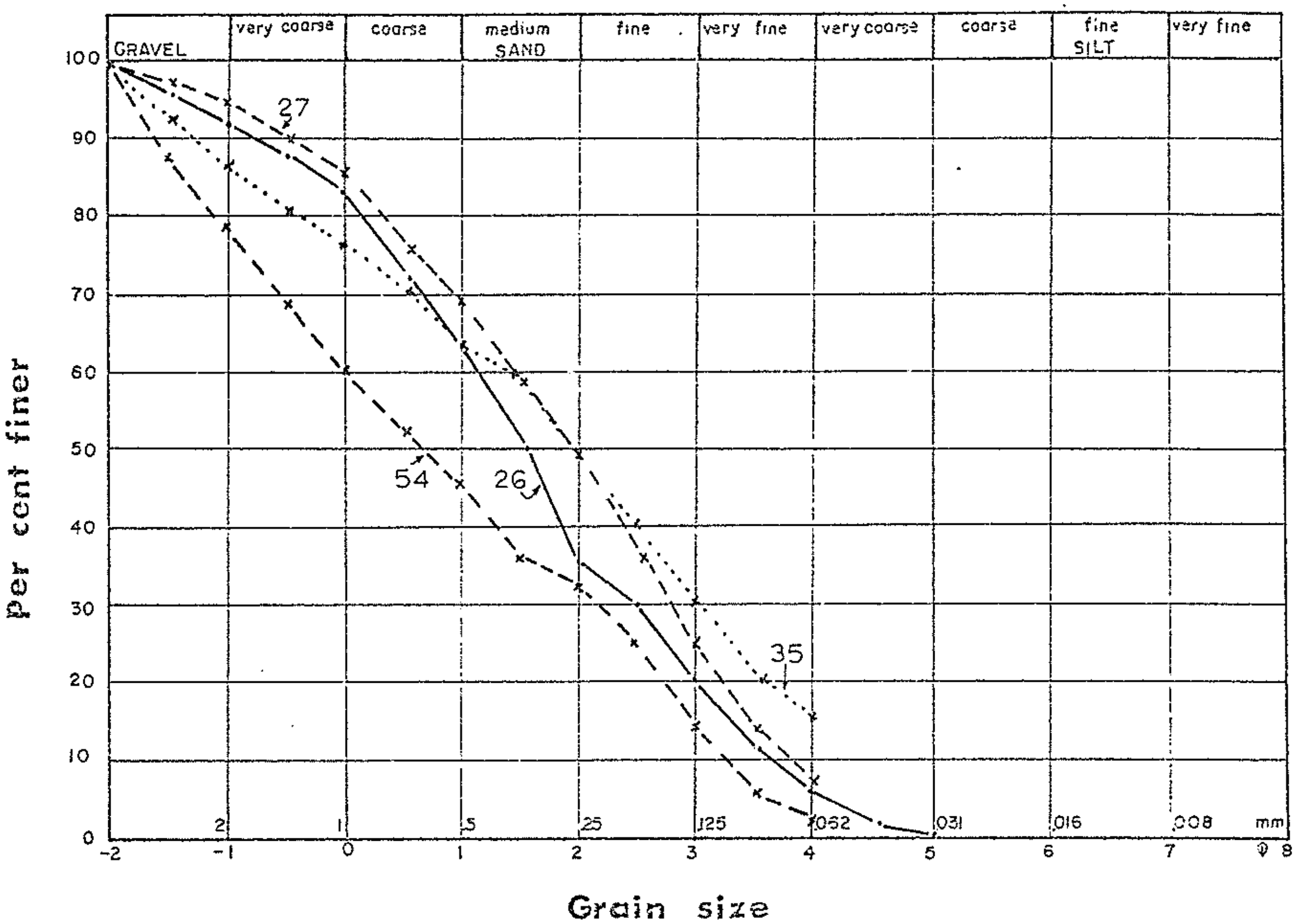
Till: Lac des Rapides mapsheet - Daigle Lake area (22 J/ 8 W)

Sample	Location	% gran	sand	si-clay	ϕ m	s	sk
70-1	North moraine	5	89	6	2.00	1.34	0.10
70-4	South moraine	5	95	0	1.10	1.42	-0.15
72-58	North moraine	4	88	8	1.80	1.58	0.11
74-13	Daigle L	10	85	5	1.27	1.72	-0.03
74-17	Daigle U	12	85	3	0.87	1.56	-0.08



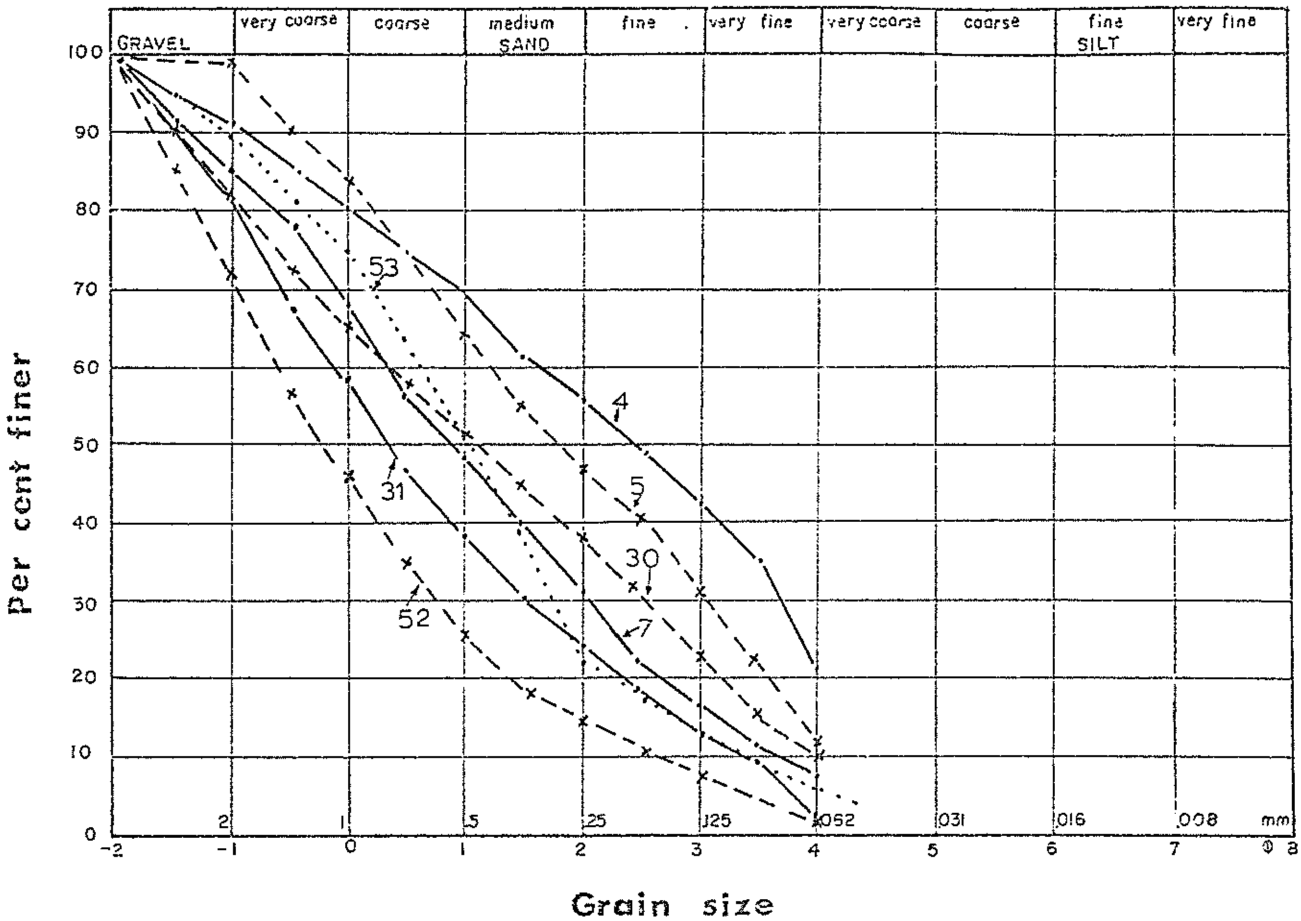
Till: Clarke City (22 J/ 2) and Lac Asquiche (22 J/ 7) mapsheets

Sample	Location	% gran	sand	si-clay	ɸ m	s	sk
71- 9	Gully hill	6	83	11	1.83	1.76	-0.01
72-47	Hall rewk	6	88	6	1.60	1.74	0.04
74-51	Hall rewk	5	93	2	1.53	1.38	-0.27



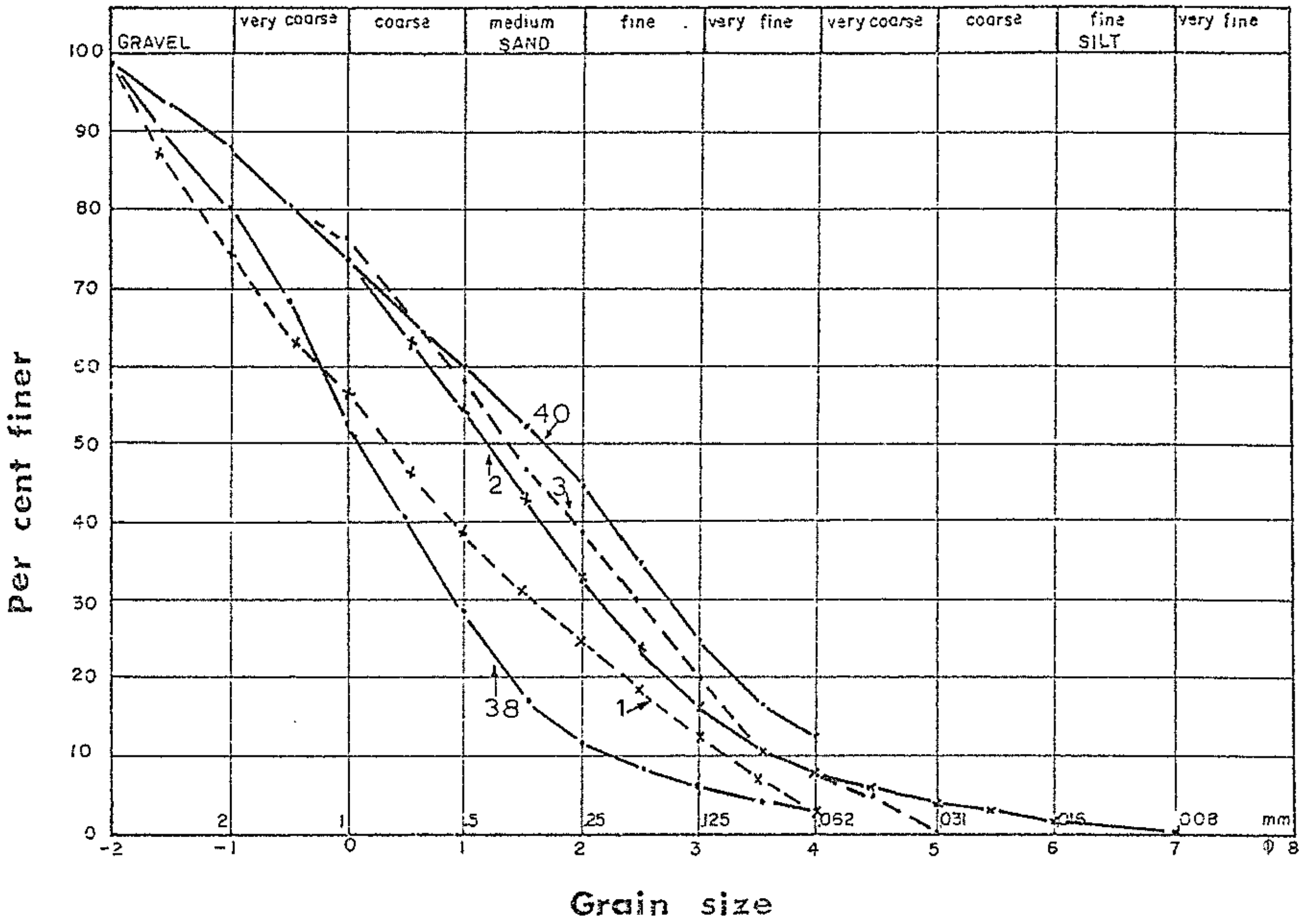
Till: Lac Vermette mapsheet (22 J/ 3 E)

Sample	Location	% gran	sand	si-clay	ϕ m	s	sk
71-26	L. Guillemette	6	88	6	1.63	1.63	-0.01
71-27	L. Guillemette	5	89	6	1.80	1.60	-0.01
74-35	Gagnon	14	70	16	1.80	2.30	-0.02
74-54	L. Guillemette	21	76	3	0.83	1.91	0.04



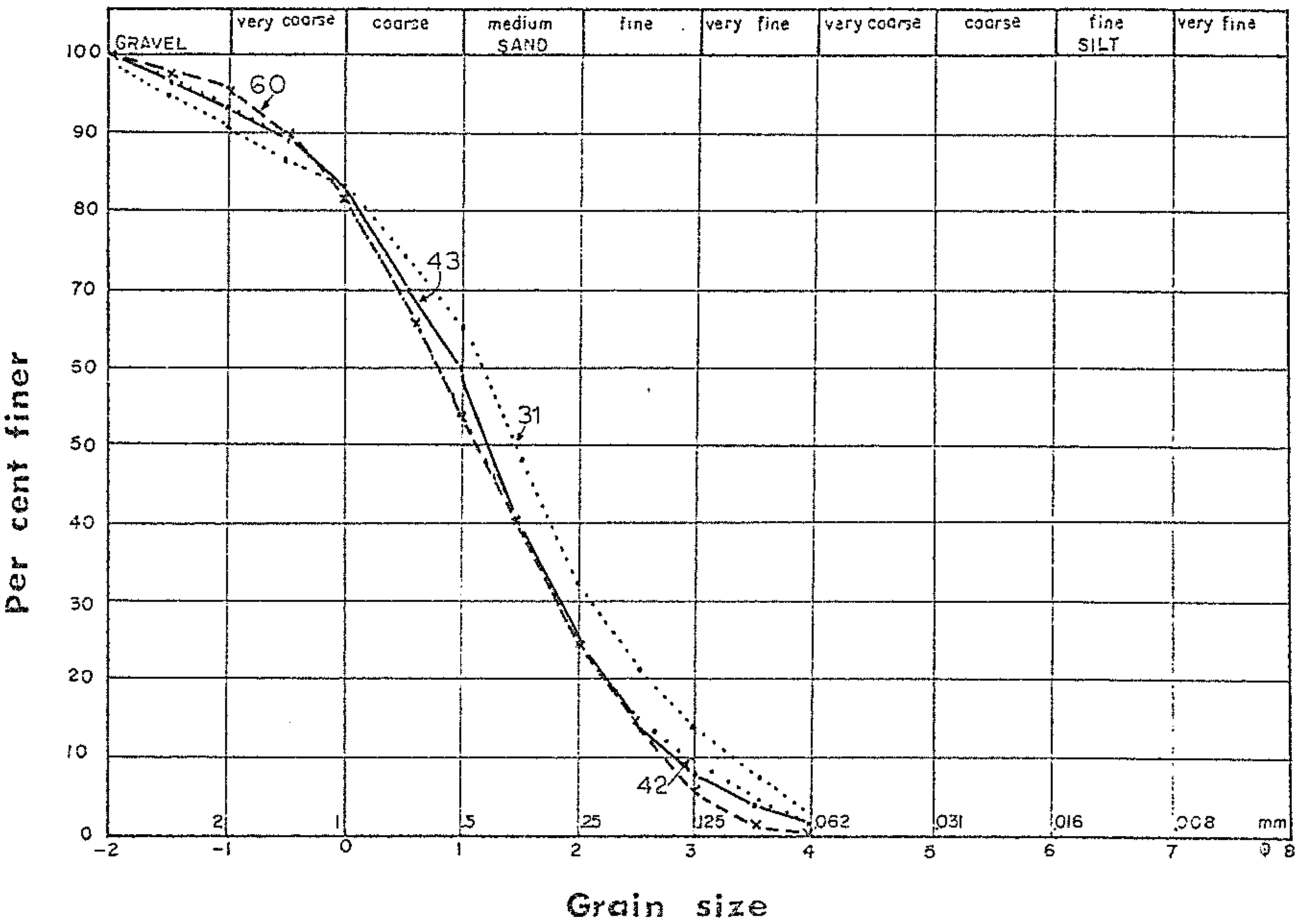
Till: Riv. Pentecôte mapsheet (22 G/14 E)

Sample	Location	% gran	sand	si-clay	ϕ m	s	sk
71-4	Riverin N	8	72	20	2.10	2.00	-0.36
71-5	Riverin S	0	90	10	1.47	1.68	0.53
71-7	Rexfor 1	14	78	8	1.13	2.04	0.17
72-52	Vachon	28	70	2	0.13	1.65	0.35
72-53	Vachon ridge	10	88	2	1.13	1.68	0.02
74-30	Riverin S	16	75	9	1.20	2.07	0.02
74-31	Vachon	16	78	6	0.73	1.83	0.24



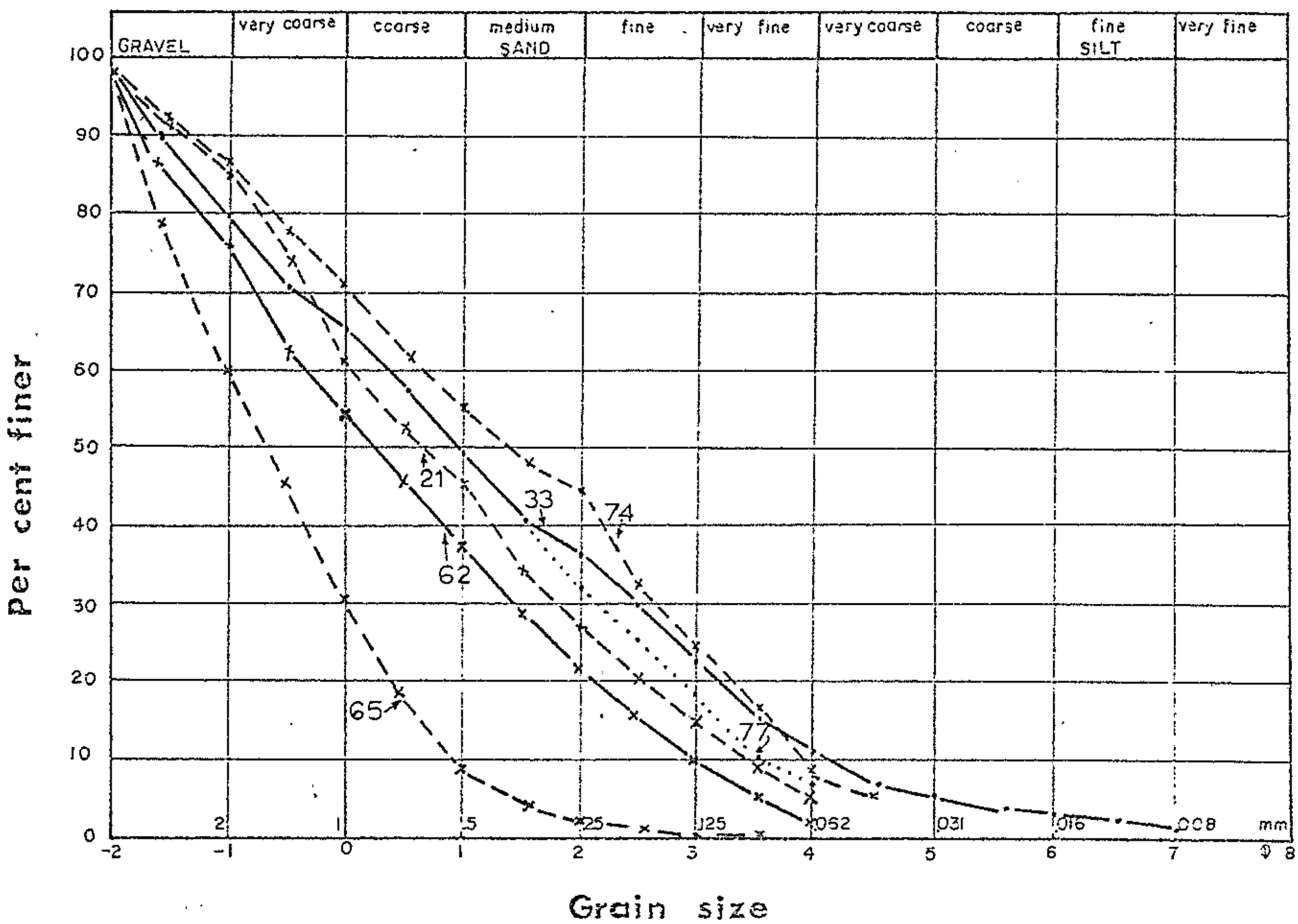
Till: Riv. Pentecôte mapsheet (22 G/14 W)

Sample	Location	% gran	sand	si-clay	ϕ m	s	sk
71 -11	L. Dupont	23	74	3	0.57	1.87	0.17
71-2	L. Dupont	11	82	7	1.27	1.83	0.02
71-3	Dupont fest.	11	81	8	1.37	1.90	-0.05
74-38	Pent. W.	18	79	3	0.20	1.47	0.13
74-40	L. Dupont	11	77	12	1.63	2.03	-0.08



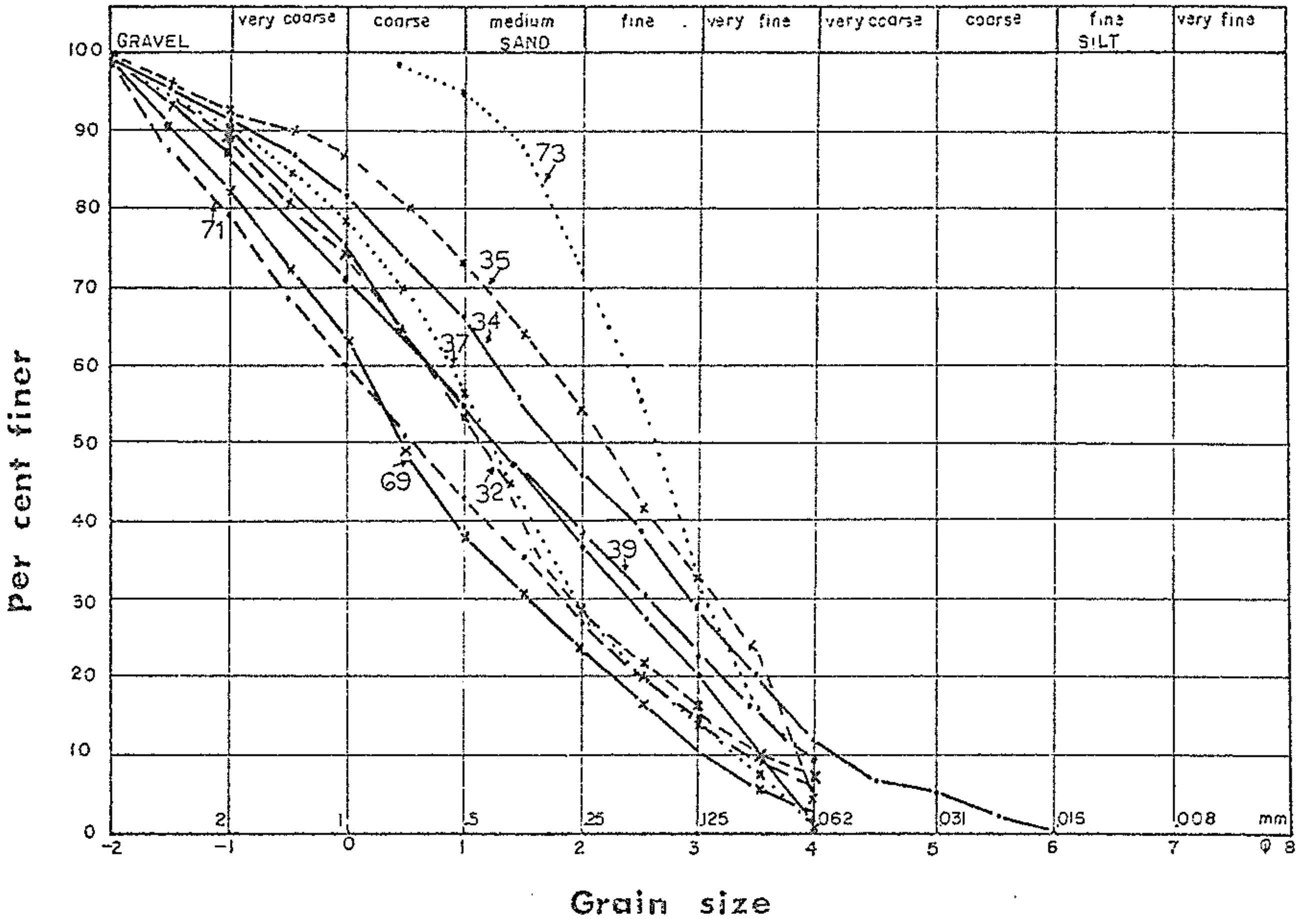
Till: Petite Riv. de la Trinité mapsheet (22 G/11)

Sample Location	% gran	sand	si-clay	ϕ m	s	sk
72-31 Ilets-Car.	8	91	1	1.47	1.53	-0.08
72-42 P.R.T. R	6	93	1	1.20	1.33	0.01
72-43 P.R.T.	6	94	0	1.23	1.25	-0.08
74-60 P.R.T. L	3	97	0	1.20	1.23	-0.03



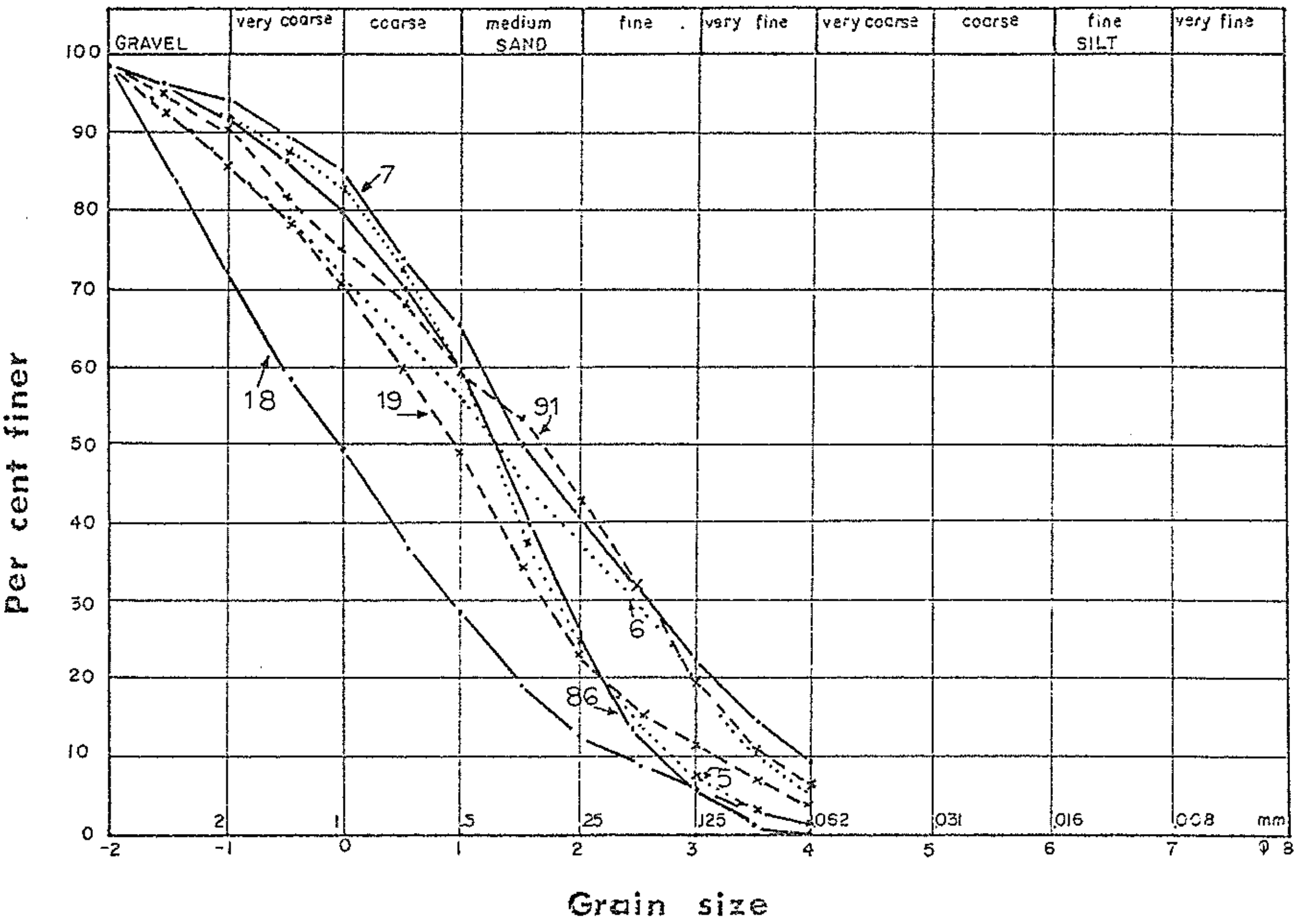
Till: Baie Trinité mapsheet (22 G/ 6)

Sample Location	% gran	sand	si-clay	ϕ m	s	sk
72-21 Double lake	19	76	5	0.87	1.94	0.10
72-33 L. Nadeau	19	71	10	1.17	2.11	0.12
74-62 Double lake	22	76	2	0.50	1.83	0.19
74-63 B.T. dump	39	61	0	-o.50	1.09	0.18
74-74 L. Nadeau	12	79	9	1.37	2.00	0.00
74-77 Crooked lake	19	71	10	1.17	2.11	0.12



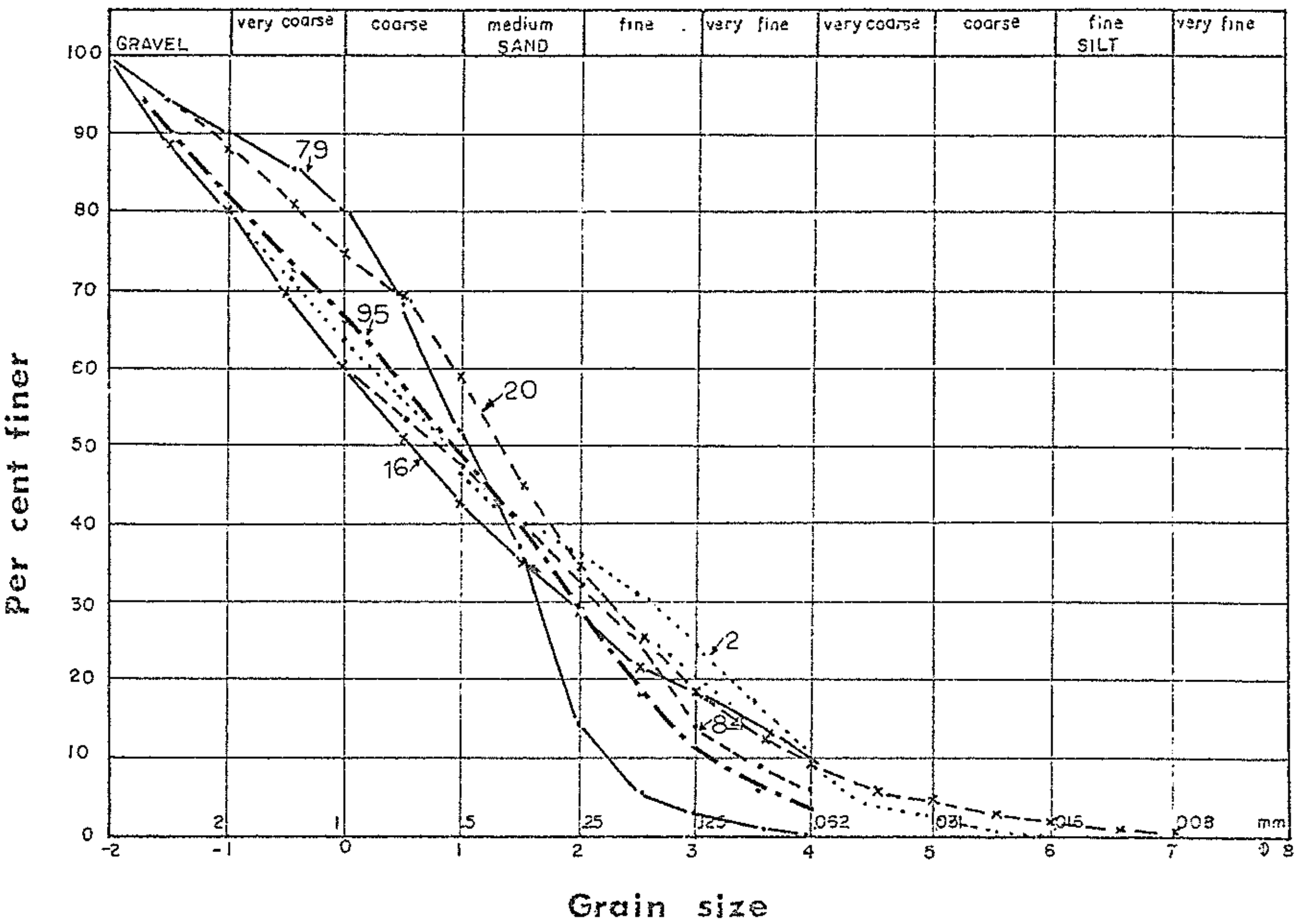
Till: Baie Trinite mapsheet-minor moraines (22 G/6)

Sample Location	% gran	sand	si-clay	φ m	s	sk
72-32 GP minor mor.	10	84	6	1.20	1.81	0.03
72-34 Pond ridge	7	81	12	1.87	1.82	0.07
72-35 Minor ridge	6	90	4	2.10	1.57	-0.26
72-37 Reworked m.m.	8	92	2	1.27	1.81	0.05
72-38 Pond ridge	12	87	1	1.27	1.75	0.02
72-39 Unmod. m.m.	10	89	1	1.33	1.67	0.00
74-69 East rewk	16	80	4	0.63	1.70	0.14
74-71 Minor ridge U	19	74	7	0.83	2.02	0.16
74-72 Minor ridge L	11	81	8	1.23	1.90	0.01
74-73 Bench mark sand	0	91	9	2.60	0.98	0.06



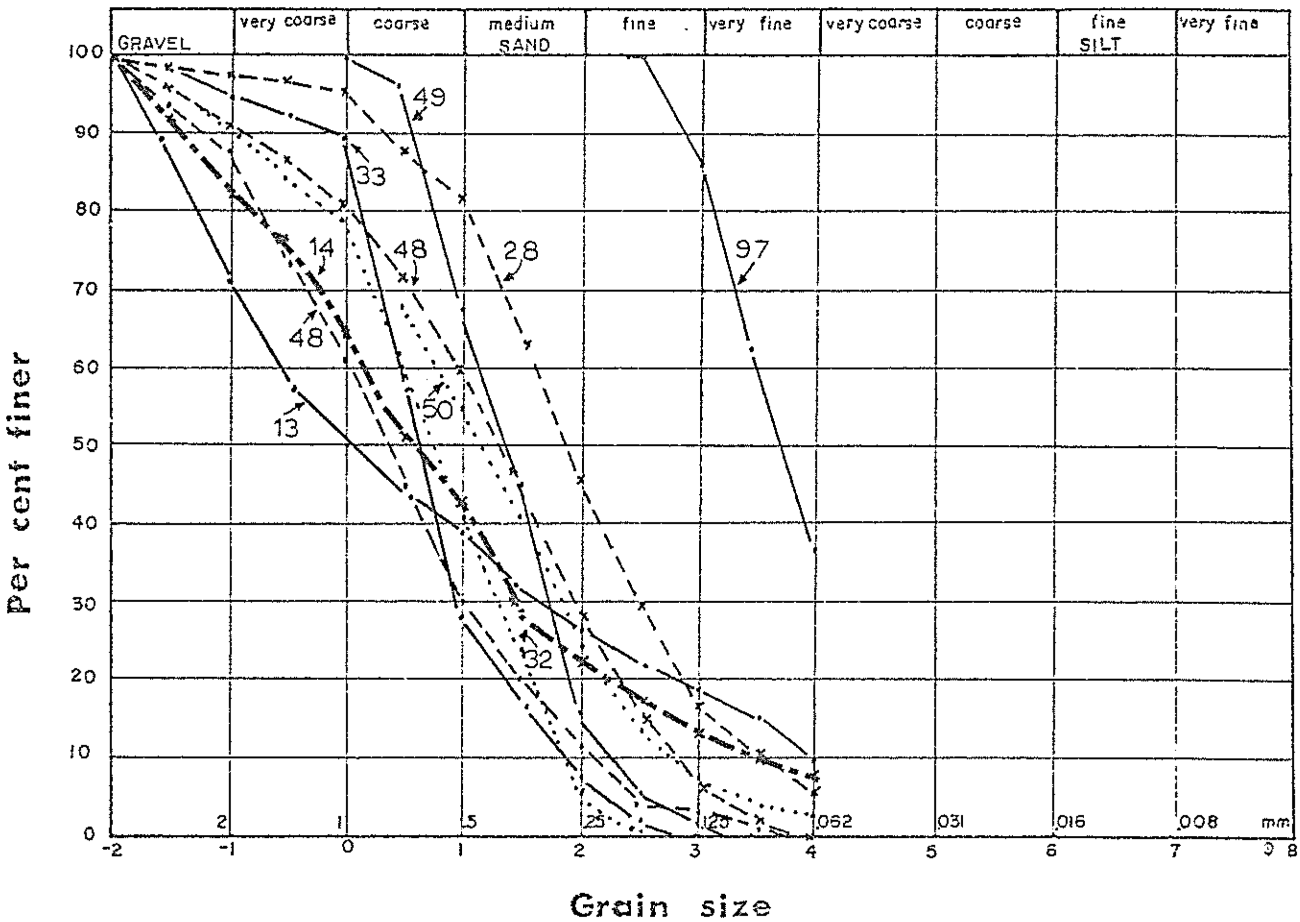
Till: Godbout mapsheet (22 G/5 W)

Sample	Location	% gran	sand	si-clay	ɸ m	s	sk
72-5	L. du Portage	8	92	0	1.10	1.31	-0.12
72-6	L. Ligne	13	83	4	1.33	1.83	-0.05
72-7	Island lake	5	89	6	1.70	1.67	0.04
72-18	Pte. Mistassini	27	71	2	0.17	1.60	0.22
72-19	L.du Portage S	13	83	4	0.97	1.64	0.02
74-86	L.du Portage W	9	91	0	1.10	1.33	-0.24
74-91	Island lake	8	87	5	1.50	0.78	-0.16



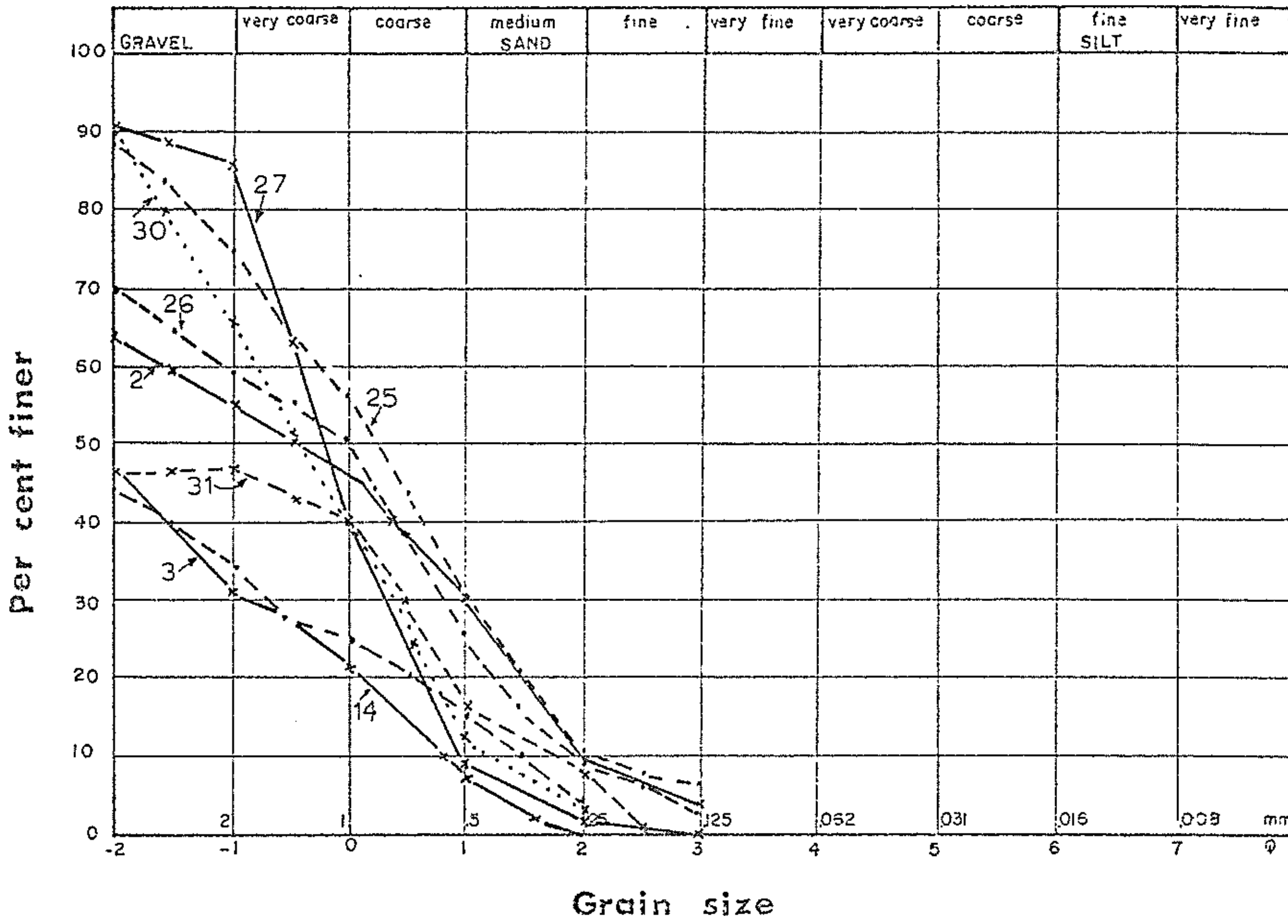
Till: Godbout mapsheet (22 G/ 5 E)

Sample	Location	% gran	sand	si-clay	ϕ m	s	sk
72-1	Powerline	17	74	9	1.13	2.04	0.09
72-2	L. Pierre U	18	72	10	0.97	1.92	0.03
72-3	L. Pierre L	10	83	7	1.60	1.80	0.06
72-16	Godbout N	18	73	9	0.90	2.00	0.23
72-20	Loop moraine	10	81	9	1.43	1.93	0.05
74-79	L. à Tabac	9	90	1	0.87	1.16	-0.19
74-84	Godbout N	18	76	6	0.93	1.91	0.07
74-95	Loop moraine	15	81	4	1.13	2.02	0.10



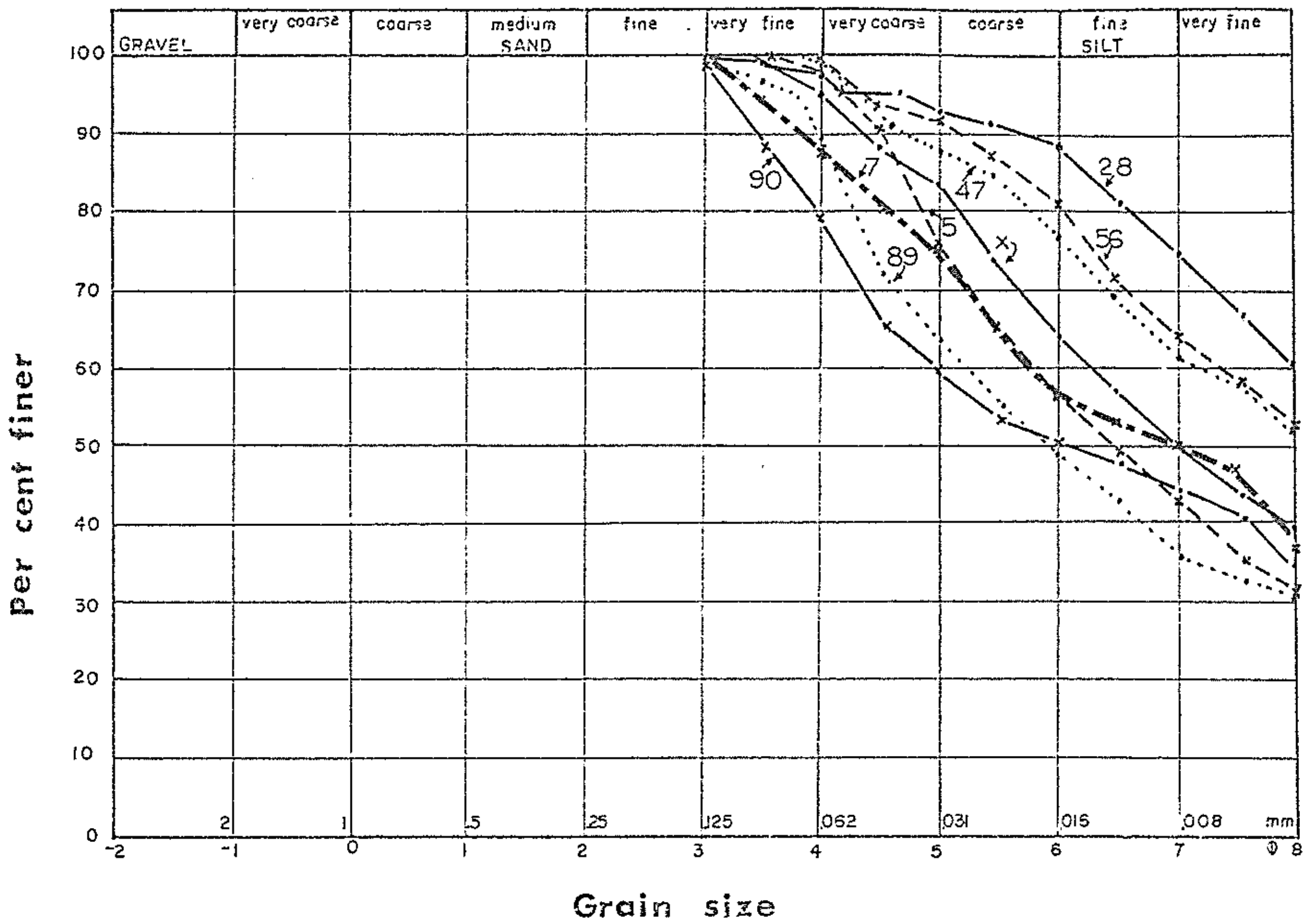
Ice contact stratified material

Sample Location	% gran	sand	si-clay	φ m	s	sk
Lac des Rapides pits (22 J/8 W)						
70-32 E side	8	92	0	0.70	0.99	-0.23
70-33 E side	0	100	0	0.80	0.84	0.31
74-48 W side	13	87	0	0.47	1.23	0.01
Lac des Rapides airstrip (22J/8 W)						
70-48 contact	8	92	0	1.23	1.39	-0.17
74-49 crossbeds	0	100	0	1.00	0.60	-
74-50 diamicton	7	92	1	1.07	1.35	-
Godbout (22G/5 W)						
72-13 grey sand	27	64	9	0.67	2.15	0.42
72-14 backwall	15	78	7	0.67	1.85	0.20
74-97 grey sand	0	66	34	0.70	-	-



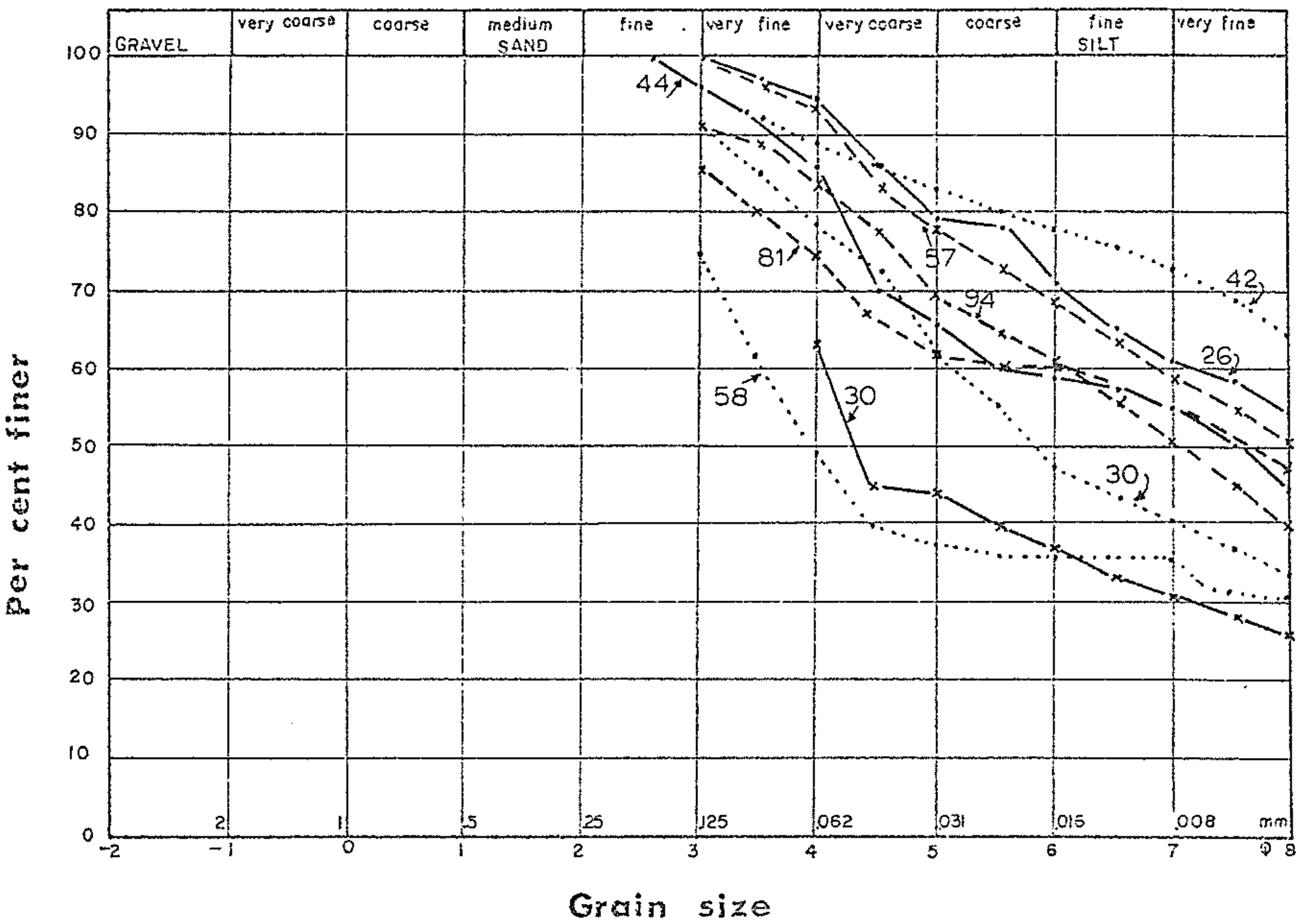
Proglacial stratified sand and gravel

Sample Location	% pebbles	granules	sand	si-clay
69-26 Daigle E GP 1	27	9	63	1
69-27 Daigle E GP 2	9	12	78	0
70-2 Daigle creek/lake	36	9	55	0
70-3 Daigle creek/lake	59	8	33	0
70-14 Daigle channel L	55	11	34	0
70-15 Daigle channel U	23	16	61	0
70-25 Deschênes rd	12	13	75	0
70-30 Daigle W	17	13	68	2
70-31 Daigle W	52	4	44	0
70-63 Daigle plain	12	9	77	2



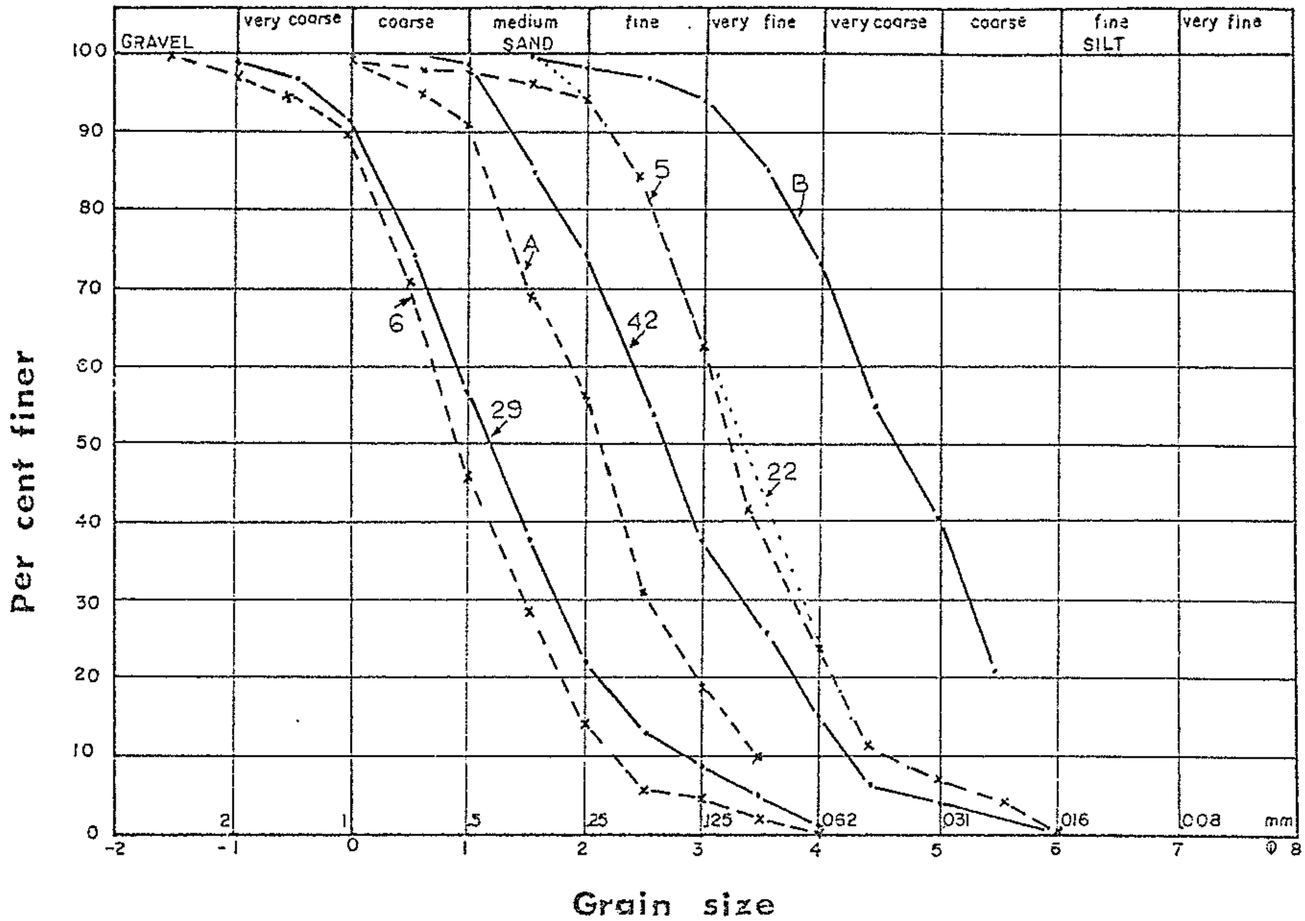
Massive offshore marine sediment

Sample	Location	% sand	silt	clay	ϕ m	s	sk
69-7	Sept-Iles	12	63	25	6.93	2.51	0.11
71-x	Sept-Iles	4	68	28	-	-	-
74-5	Moisie gully	5	73	22	7.00	2.55	0.15
74-28	Sept-Iles#4	3	47	50	9.50	3.45	0.11
74-47	Sept-Iles stable	2	54	44	8.70	3.65	0.13
74-56	Pt. Cartier W	2	58	40	8.40	2.70	-0.06
74-89	St. Nicholas L	10	65	25	6.83	3.00	0.18
74-90	St. Nicholas U	24	48	28	6.70	3.20	0.14
x	Townsite at -236'	-	-	-	6.70	2.06	0.20



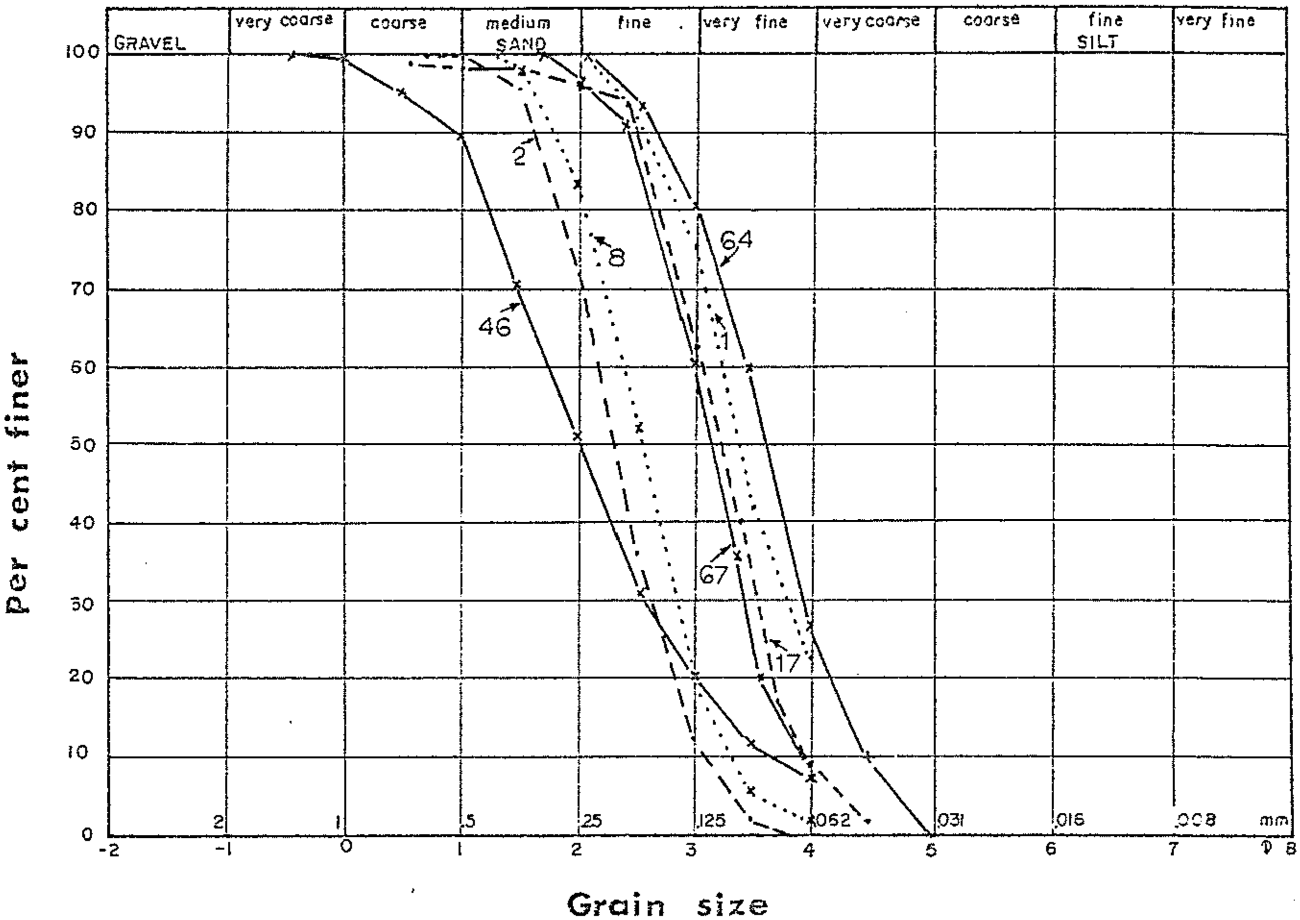
Banded offshore marine sediment

Sample	Location	% sand	silt	clay	ϕ m	s	sk
69-30	Mile 9	22	53	25	6.47	2.81	0.33
72-30	Ilets Caribou	36	41	23	-	-	-
74-26	Arnaud/Rapides	7	46	47	8.43	3.75	0.03
74-42	Pentecôte W	11	35	54	9.47	4.65	-0.01
74-44	Mile 10	15	46	39	7.83	3.85	0.05
74-57	Vachon	7	52	41	8.40	4.05	0.06
74-58	Pet. Riv. Trinité	52	22	26	5.83	4.15	0.36
74-94	Franquelin	16	53	31	7.10	3.25	0.08
74-81	Ilets Caribou	25	34	41	7.83	4.75	0.05



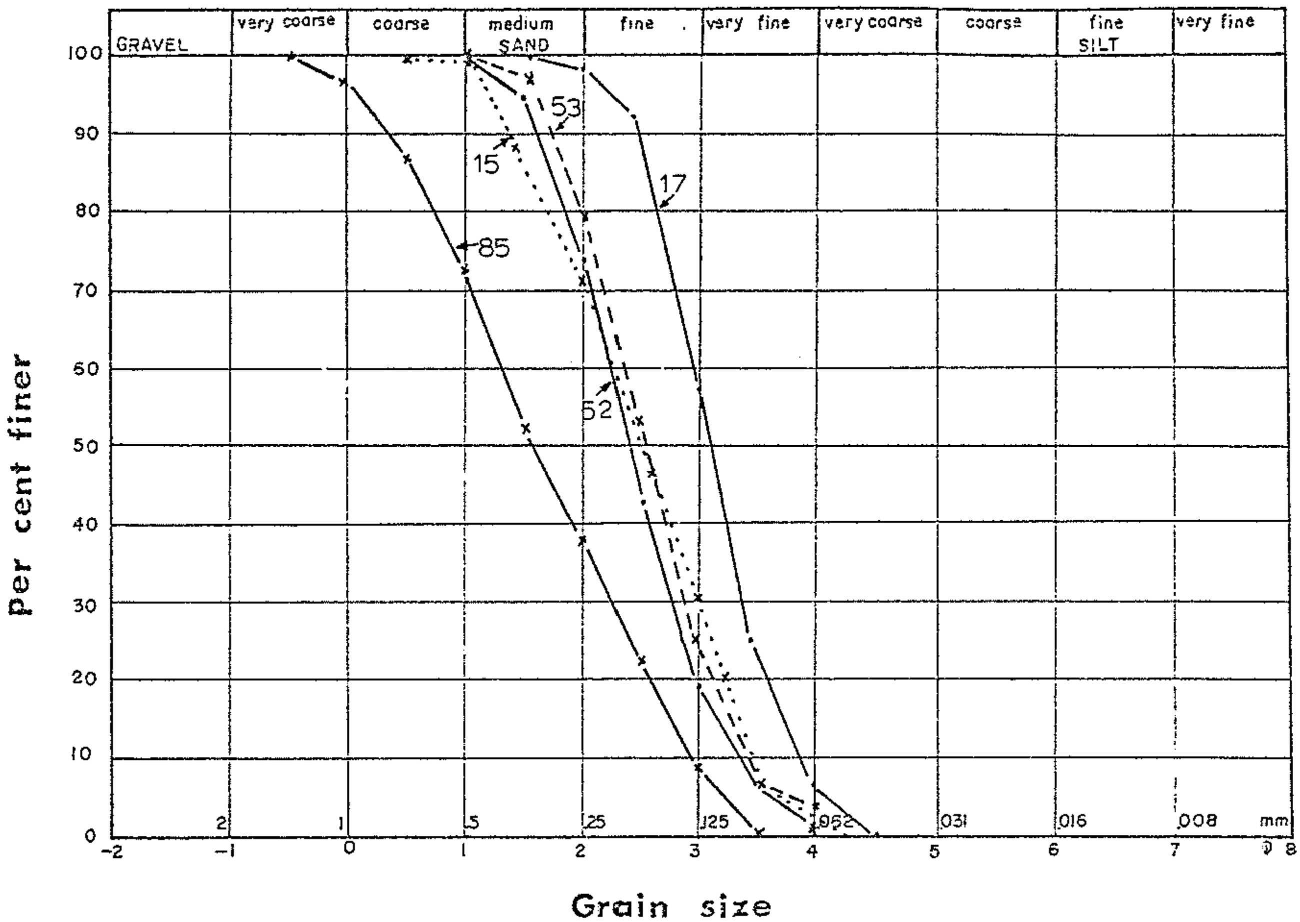
Estuarine sand - Moisie River samples

Sample	Location	% sand	silt	clay	Φ m	s	sk
69-5	Village	78	22	0	3.30	0.90	0.07
69-42	Laurent Val	85	15	0	2.83	0.95	-0.04
70-22	Village	81	19	0	4.30	0.71	-0.04
74-6	Gully sand	99	1	0	1.00	0.87	0.23
74-29	Gully alluv.	100	0	0	1.27	1.26	0.04
A	F/S at 40'	90	10	0	2.56	0.96	-
B	F/S at 60'	20	80	-	4.70	0.53	-



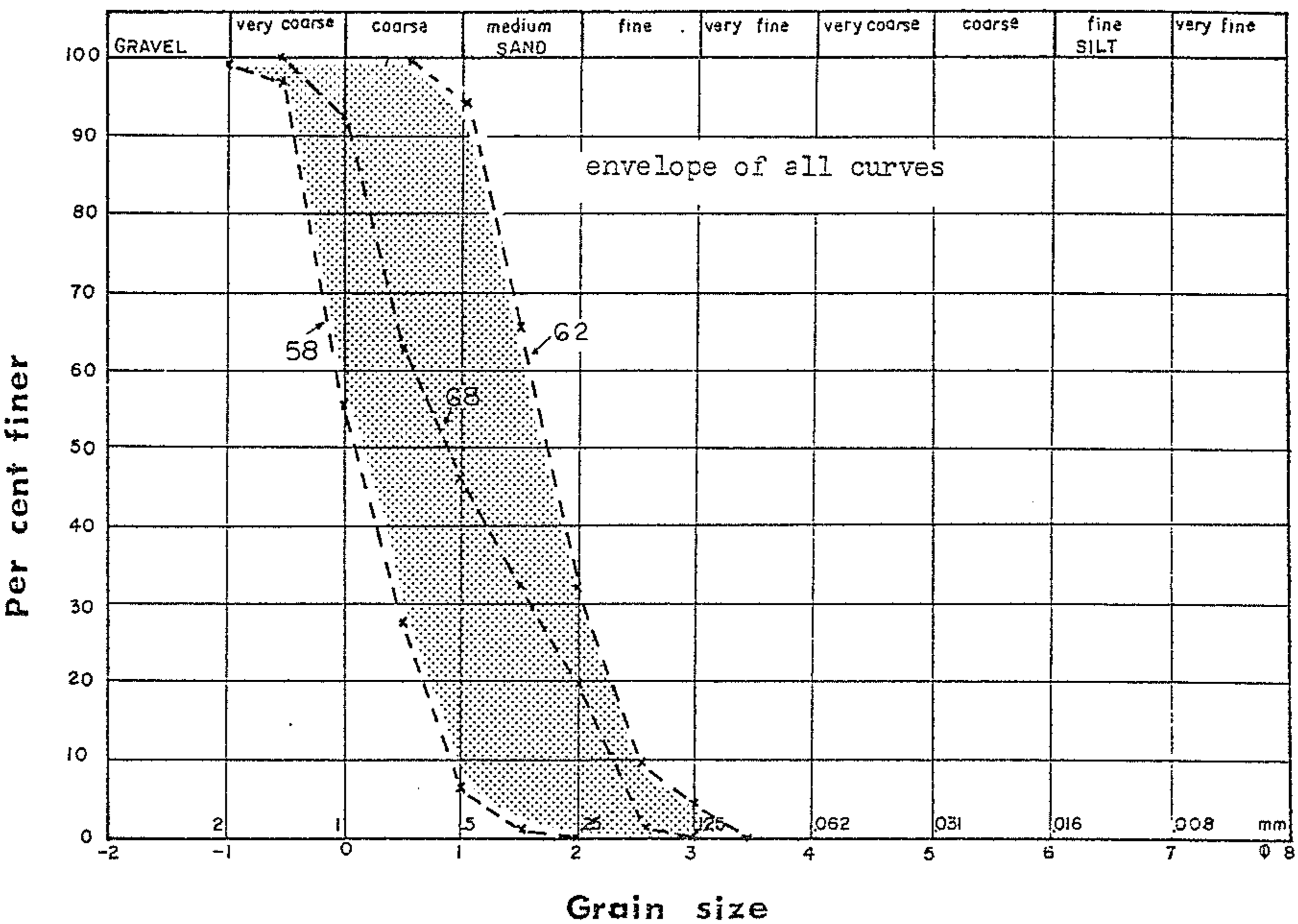
Estuarine sand - Sept-Iles airport samples

Sample Location	% sand	silt	clay	ϕ m	s	sk
69-17 Maliotenam	88	12	0	3.20	0.54	-0.03
70-46 Maliotenam	93	7	0	3.13	1.12	0.24
70-64 Airport L	77	23	0	4.70	0.74	0.08
70-67 Airport M	93	7	0	4.30	0.52	-0.06
74-1 Airport base	80	20	0	3.40	0.38	0.10
74-2 Airport M	100	0	0	2.13	0.43	-0.16
74-8 Airport M	99	1	0	2.43	0.68	0.05
C Golder townsite -40'	65	35	0	3.73	1.15	0.54
D Golder at -18m	100	0	0	3.07	0.82	0.09
E Golder ar - 30m	98	2	0	3.40	0.53	0.22



Estuarine sand — Ste Marguerite River and Godbout areas

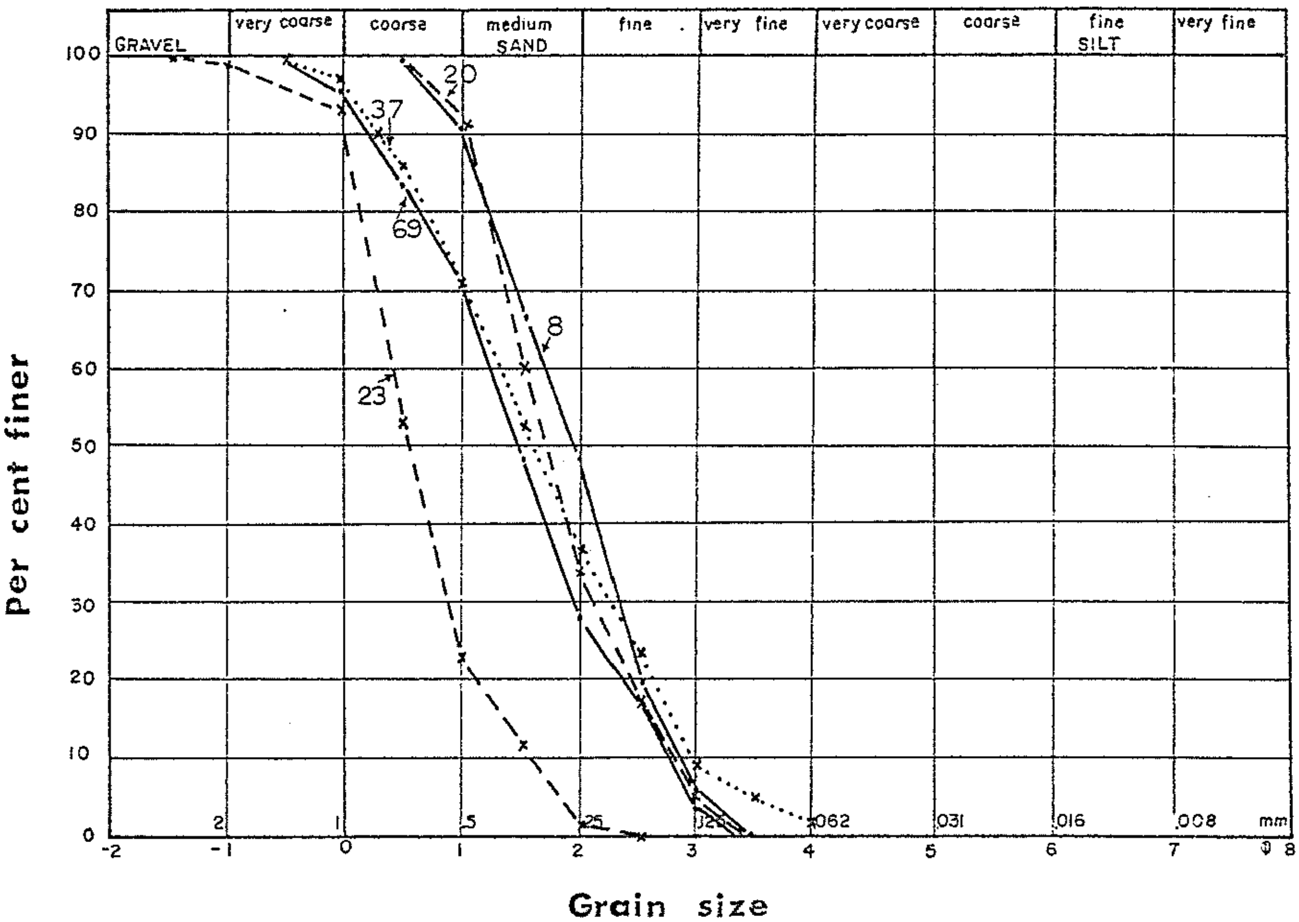
Sample	Location	% sand	silt	clay	ϕ m	s	sk
71-15	Pointe Noire	98	2	0	2.40	0.83	-0.17
71-17	North pits	95	5	0	3.00	0.52	0.06
74-52	Pointe Noire	99	1	0	2.37	0.67	0.24
74-53	roadcut dam	97	3	0	2.50	0.70	0.11
74-85	Godbout	100	0	0	1.60	1.02	0.06



Beach sand

Sample	Location	ϕ	m	s	sk	k
69-6	Vieux post	-0.47	0.46	0.10	1.56	
69-18	sand waves	0.87	0.78	0.04	1.02	
69-38	farmer	1.93	0.65	-0.02	0.82	
69-46	airport	1.53	0.43	-0.13	1.16	
70-10	M 12 midsl.	-0.83	0.57	0.19	0.92	
70-16	Daigle rid.	-0.90	0.69	0.12	1.09	
70-21	Arn/Rap.	1.53	0.56	0.02	0.97	
70-22	coast 150′	1.17	0.71	0.20	1.41	
70-26	Moisie 81′	0.00	1.03	0.25	1.02	
70-36	pen scarp	2.53	0.68	-0.07	1.29	
70-43	spit	1.60	0.92	0.16	1.13	
70-44	Daigle 1.3	0.63	0.79	-0.10	1.07	
70-45	Daigle 1.3	1.50	0.75	-0.07	0.94	
70-50	M 12 limit	0.00	0.41	0.14	1.15	

Sample	Location	ϕ	m	s	sk	k
70-52	M 12 low	-0.63	0.65	0.12	0.75	
70-53	"	-0.17	0.65	-0.15	1.35	
70-54	Daig. ridge	.03	0.69	0.15	0.78	
70-56	Daig. hill	-.17	0.50	-0.13	1.17	
70-58	"	-1.23	0.69	0.00	1.23	
70-59	"	-0.23	0.60	-0.27	1.35	
70-61	"	0.60	0.77	0.14	1.33	
70-62	borrow 2	0.13	0.48	0.20	1.16	
70-68	Maltais	0.97	0.77	0.08	0.78	
70-71	M 3	0.90	0.89	-0.09	0.99	



Aeolian sand

Sample	Location	ϕ m	s	sk	k
69-8	Sept-Iles	1.97	0.71	0.01	0.90
69-20	"	1.97	0.74	0.31	0.86
69-37	"	1.90	0.91	0.09	1.19
69-43	"	–	–	–	–
72-73	B. Trinité	–	–	–	–

APPENDIX E Additional Geotechnical Data

E-1 Permeability

Permeability values of sandy materials reported in the text were obtained from tables constructed by Beard and Weyl (1973). They found that the theoretical equations of Krumbein and Monk (1942), which are based on grain size and sorting, correspond well with both artificially mixed and packed sand, and with field measurements. Permeability was also calculated from grading curves by the method proposed by Terzaghi and Peck (1967, p. 50).

Permeability calculated by these two methods fall between values calculated from field (pumping) and laboratory (permeameter) tests (performed by Iron Ore Company, 1970) and the figures reported are expected to be correct within one order of magnitude.

E-2 Density and penetration resistance

Density and penetration values were acquired

1. to obtain general information relating to the state of the material and its approximate unconfined compressive strength.
2. for till, to compare one site with another and to see if there were significant vertical changes in exposures where no stratigraphic breaks were visible. It was thought that, if a layer of till from one glaciation were over-ridden by a second glacier with the same provenance, the materials would be texturally and petrographically indistinguishable, but that the first till might have a greater density because of compaction by the overriding ice. It was also thought that density determinations might support other types of data in distinguishing between ablation-flow, basal melt out, and lodgement tills.

Penetration tests were performed with a Vicksburg-type proving ring cone penetrometer. Twenty-five readings were taken at each site; the average and range were considered in analyses. The main problem encountered with this instrument was that its accuracy is determined by the operator's ability to apply stress at an even rate. This was very difficult because most readings were directed horizontally onto a cleaned exposure, rather than vertically into the soil.

A Soiltest pocket penetrometer was used on fine materials in addition to the cone penetrometer in order to compare the two instruments. The pocket instruments gave more consistent results because they were easier to apply at a constant rate.

In situ field density values were obtained by forcing a cylinder of known volume into the soil and cutting around it so that the cylinder and contained soil could be extracted. This method worked well for fine sand and clayey material, and was satisfactory for the medium to coarse sand; however, it was not satisfactory for tills, because the cylinder could not be forced into the stony soil without disturbing both the pebbles and the sandy matrix.

E-3 Shear strength measurements

Shear strength values for fine-grained sediment were obtained with portable shear vane kits designed by Geonor and Pilcon. The 4 cm Geonor vane with 50 cm and 1 m extension rods were most frequently used. A pocket penetrometer and Torvane were also used to determine unconfined compressive and shear strengths when the larger vanes were not available. The Geonor and Pilcon values were considerably more accurate (i.e. produced results that were consistent in the field and reproduceable in the laboratory), and more precise.